technical note

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Atlanta Tower Simulation
Volume I

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November 1989

DOT/FAA/CT-TN89/27, I

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16. Abstract

At the request of the Atlanta (ATL) Facility, The Technical Center conducted dynamic real-time simulations of selected aspects of the Atlanta Tower's Airport Enhancement Plan. Atlanta controllers, who served as subjects, evaluated traffic flow to a three runway configuration with both a third parallel runway, 3000 feet south of existing runway 9R and a 30 degree converging runway. Large numbers of blunders (deviations of inbound aircraft away from their assigned localizer paths) were introduced to exercise the proposed system. In over 90 blunders during approaches to the third parallel runway, 5 resulted in closure distances between aircraft small enough to merit detailed analysis. The smallest horizontal distance involved 30 degree blunders across the 3000-foot separation with four of these also simulating a complete loss of communications. The overall simulation results demonstrated the controllers' ability to maintain an orderly flow of traffic to both the triple parallel and converging runway configurations. When repeatedly challenged by the unlikely combination of 30 degree NORDO blunders, 94 percent of were managed without incident.

The decision on runway separation distances for new constuction or runways in Atlanta should not be based solely on the results of this simulation. Additional relevant data is now available which could affect the results, including navigation data from Chicago O'Hare, and automation and radar data being collected at Memphis, Tenn. and Raleigh-Durham, N.C.

Potential capacity restraints are possible based on a combination of flight technical error around the localizer and a normal operating zone reduced to 500 feet. There are a number of technological innovations ongoing to be considered that are being tested by the high update radar sensors at Raliegh-Durham and Memphis and the associated automation features.

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PREFACE

This report documents a series of air traffic control (ATC) simulations performed at the Federal Aviation Administration (FAA) Technical Center. These real-time ATC exercises were conducted to evaluate selected options for enhancing the Atlanta Hartsfield International Airport. This report is organized in two volumes.

Volume I contains the main body of the report. It includes a detailed description of the objectives of the study and of the technical approach and test methods that were used. In addition, the combined results of the study and conclusions are presented.

Volume II consists of a set of four appendices to the report which are referenced in Volume I. These appendices contain the graphic and quantitative plots for all of the "conflicts" which contributed to the analyses of the proposed ATL modifications.

ACKNOWLEDGEMENTS

This project would not have been possible without the continual support of Jeff Griffith from the Atlanta TRACON, representing the Southern Region, who was actively involved from the initial concept, through planning the airspace, routes, and traffic samples, and, later, Barbara Green for the conduct of the simulation.

The entire staff of the National Airspace System Simulation Facility (NSSF) made this simulation possible. Special thanks go to George Kupp, assisted by Hank Smallacombe, the controllers who tested and refined the system, trained the simulator operators and executed the scenarios; John Dempsey who kept the displays running and did much of the troubleshooting; and Dan Warburton, Don Anderson, and Dorothy Talvaccia who modified the software to provide the special features needed.

Consultants involved in the preparation of this report include Dr. Norm Lane and Dr. Robert Wherry who developed the Projected Closest Point of Aproach (PCPA) metric and assisted in the analysis and interpretation of the data, and Colonel Paul Stringer who assisted in the assessment of the operational implications of the study.

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EXECUTIVE SUMMARY

The Federal Aviation Administration Technical Center conducted a series of dynamic, real-time simulations of selected alternatives for the proposed traffic enhancement modifications for Atlanta's Hartsfield International Airport. The simulations included feeder operations to two and to three (triples) runways and included the simulation of the monitoring positions for both parallel and converging triples. Journeyman controllers from the Atlanta TRACON served as simulation subjects and manned the test positions. Two configurations of additional runways were evaluated; a third parallel runway (runway 10) situated 3000 feet south of the existing runway and a 30 degree converging runway (runway 6) which was also positioned south of runway 9R.

Since parallel instrument approaches are not presently approved to runways that are separated by less than 4300 feet, the capabilities of the Atlanta configuration which was simulated were enhanced by the addition of a number of special features: (1) a 1-second update rate, high resolution radar (modeled after the one that is currently being evaluated at Raleigh/Durham), (2) an automated alert to notify the controllers when an aircraft entered the No Transgression Zone, and (3) an expanded scale on the radar display which would highlight an aircraft's deviation from its assigned localizer path.

The primary safety concern associated with simultaneous approaches to closely spaced parallel runways revolves around the controllers' ability to resolve conflicts generated by aircraft which deviate markedly from their assigned tracks (blunder). For the simulation to challenge Atlanta's proposed 3000-foot separation parallel runway configuration, selected aircraft were directed to deviate (blunder), in accordance with a structured simulation scenario, from their assigned approach tracks by either 10, 20, or 30 degrees. Forty percent of these blundering aircraft also simulated a complete failure of their communication systems, or some other unspecified flight deck problem, which resulted in their failing to respond to any subsequent controller inquiries and/or clearances.

With the converging runway configuration, the primary concern was the conflicts resulting from missed approaches to runway 6 and simultaneous missed approaches to 6 and 9L.

The Atlanta controllers generally agreed that the proposed configuration of feeder fixes presented no significant problems and felt confident that they could maintain a smooth and safe flow of traffic through the ATL terminal area to initiate approaches to either the third, 3000-foot separation parallel runway, or to the converging runway(s). A sampling of the converging, should yield a minimum increase in capacity of 40 percent. Part of this enhanced capacity would be the result of simply having an additional runway, but part would be due to the ability to segregate the slower turboprop and business jet traffic which would be made possible by the added new, shorter runway(s). The converging triple configuration presented no special problems but should not be expected to provide the same increase in capacity as that experienced with the addition of a third parallel. Feeder complexity would be greater for the converging configuration. The converging missed approach procedures would require higher minimums with the capacity of the converging runway significantly restricted by Instrument Flight Rules weather conditions and/or simultaneous departures on runway 9L.

The results obtained in the simulation of the triple parallel configuration must be interpreted with care. Blunders of the severity of those introduced into the Atlanta simulation are extremely rare events in a real world, operational environment. When challenged by over 100 blunders, with many threatened aircraft initially separated by only 3000 feet, no simulated collisions were recorded. However, for several reasons, this level of performance should be considered as the upper bound for blunders as severe as those that were simulated. First, the simulated parallel approaches were flown with minimal flight technical error (random variations around the localizer center line). Not only would this lack of normal deviations make the onset of a real blunder easier for the subject controllers to detect but, with a normal operating zone of only 500 feet on the left of runway 10 and the right of runway 9L, a more realistic simulation of normal deviations could well have produced a significant number of false alarms (NTZ entry alerts) when no blunder was actually taking place. This would tend not only to reduce the value of this alert (the "cry wolf" syndrome), but could result in the controllers diverting aircraft on other runways, without true cause, which could lead to unnecessary delays, additional secondary conflicts, and/or a failure to respond to a valid blunder.[1]

Another limitation upon the translation of simulation results into valid projections of actual field performance comes from the unrealistic expectations which the subject controllers can develop while working in the laboratory environment. In the Atlanta simulation, blunders occurred at intervals ranging from 1 to 5 minutes. Thus, the controllers were not only anticipating them, but were, undoubtedly, continuously preplanning their strategy for handling the next blunder if, and when, it occurred. The responses of a controller in the field, where such blunders are extremely rare, could not be expected to be as effective.[1]

[1] The use of Raleigh Durham and Memphis automation features, if successfully tested would reduce, if not eliminate, these concerns.

While no simulation can serve as a guarantee of future safety, the results of this simulation certainly do not, in any way, preclude the implementation of the closely spaced parallel operations which have been proposed for Atlanta. When challenged by repeated 30 degree NORDO blunders, the controllers found the system usable and, indeed, found it to be better than the current configuration when operating under more realistic conditions.

BACKGROUND

An analysis of the operations at Atlanta's Hartsfield International Airport (ATL), published by personnel of the Atlanta Tower in August 1987, made it clear that a "dramatic increase" could be expected in the near term in both overall volume and, in particular, in the amount of commuter airline traffic coming into ATL to connect with longer distance flights. According to this report, in the 12 months prior to its publication, ATL had handled 802,497 operations with 23 percent of these operations logged by commuter aircraft in contrast to the 2 percent commuter share which was recorded in 1975. This trend toward increasing commuter activity prompted the personnel of the Atlanta Tower to explore a number of alternative modifications of ATL's current operations which would allow this facility to manage this increasing traffic load while maintaining its current high level of safety and efficiency. The modification most prominently considered by this report involved the construction of a new runway complex, designed primarily for the use of commuter aircraft, which would be positioned south of ATL's current runway 9R/27L. The existing configuration (see figure 1) and operational usage of the Atlanta Hartsfield International Airport has been described as follows in a working paper prepared for the Federal Aviation Administration by The MITRE Corporation (July 1988):

"The current configuration at the Atlanta Hartsfield International Airport consists of two pairs of closely-spaced parallel runways [with] the spacing between the north runways (8L/26R and 8R/26L) 1000 feet; between the south runways (9L/27R and 9R/27L), 1050 feet; and between the inner runways (8R/26L and 9L/27R), 4400 feet. All of the runways are Instrument Landing System (ILS)-equipped at both ends. Runways 8L and 8R are Category II-equipped; 9R is Category IIIA-equipped."

"Because the spacing of the inner runways exceeds the minimum spacing of 4300 feet required for simultaneous independent parallel approaches, independent arrival operations can be conducted using either of the north runways with either of the south ones. During typical operations, arrivals use the outer runways and departures use the inner runways. This has a number of operational advantages such as providing the largest spacing between approach paths and allowing departures to use the longer runways."

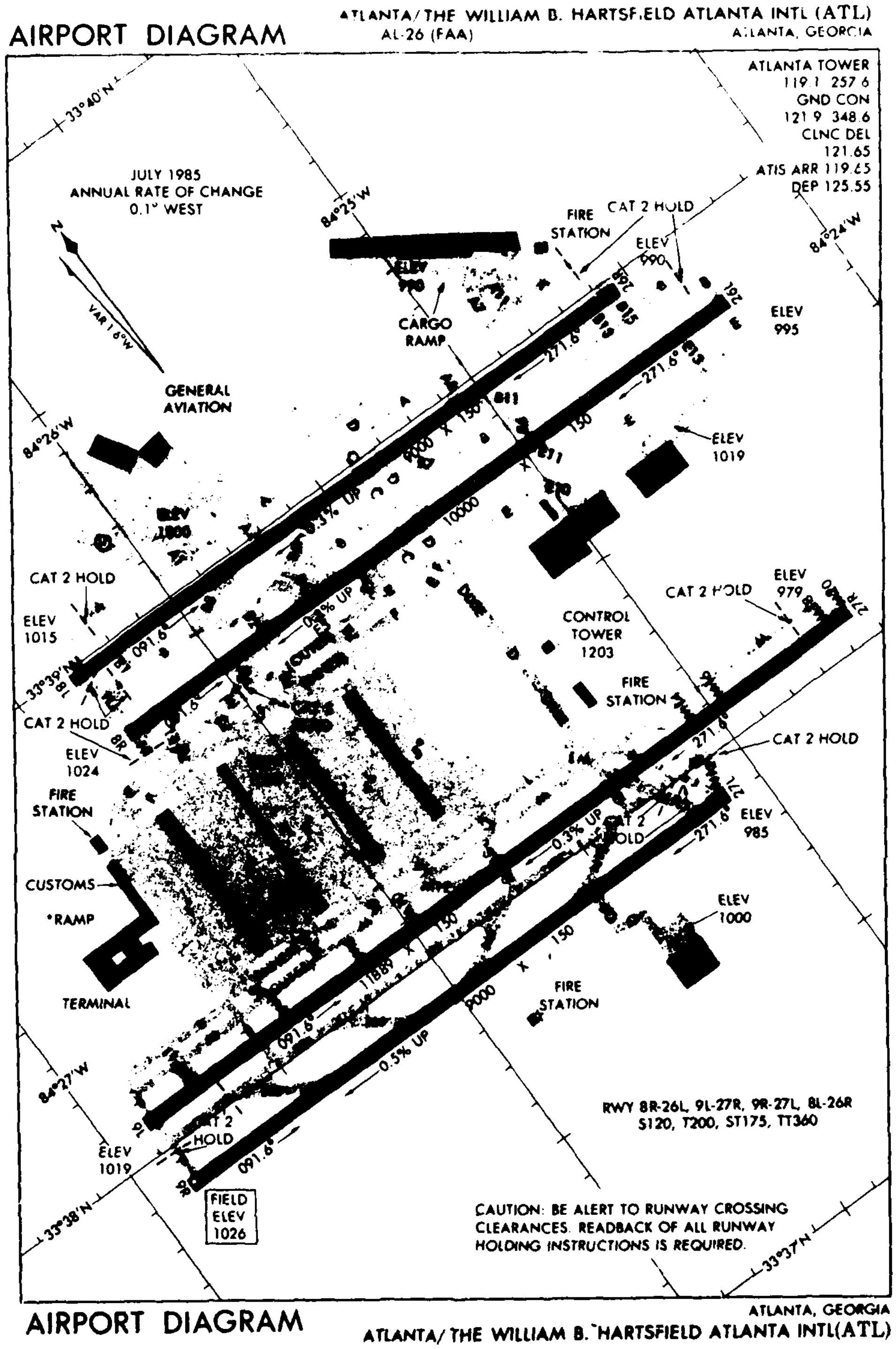

FIGURE 1. CURRENT ATLANTA CONFIGURATION

The August 1987 Atlanta Tower report proposed a commuter aircraft runway complex of three runways; one east/west runway and two diagonal runways (see figure 2). It was contended that this configuration would allow for departures on the east/west runway and converging arrivals on the diagonal runway that corresponded to the parallel runways in use at the time.

The Atlanta Tower study also included two alternative proposals; (1) the establishment of a single parallel runway to be constructed 4300 feet south of the existing runway 9R/27L; and (2) building a commuter aircraft runway parallel to and 3000 feet south of runway 9R/27L. Consideration of this latter configuration was reported to have been dictated by the availability of expansion property and the Atlanta Tower's awareness that the FAA was planning operational tests (in Memphis, Tennessee, and Raleigh-Durham, North Carolina) to evaluate the feasibility of using simultaneous ILS approaches to parallel runways separated by as little as 3000 feet. In October 1987, 2 months after the publication of the Atlanta Tower report, the Director of the Southern Region (ASO-1), Garland P. Castleberry, forwarded the report to the Administrator (AOA-1) with a request that the live testing proposed for Raleigh-Durham include evaluations of the converging and the 3000-foot separation parallel runway configurations proposed for ATL.

In November of the same year (1987), a Committee, established by the city of Atlanta in conjunction with the airlines, eliminated the concept of the proposed construction of a three runway complex and reduced the number of alternatives to three; all proposed for installation south of the existing runways:

1. A pair of diagonal runways converging on the existing runways at an angle of 30 degrees;

2. A single parallel runway spaced 3000 feet south of the existing runways; and

3. A single parallel runway spaced 4300 feet south of the existing runways.

The Committee further dictated that any additions to the existing runway configuration must be capable of supporting full Instrument Flight Rules (IFR) operations down to minimums of a 200-foot ceiling and 1/2-mile visibility, and that the parallel runway options be able to support, if required, triple IFR operations. This latter constraint was based upon the committee's well founded recognition that the cost effectiveness of any runway addition(s) would rest upon its ability to consistently support an increase in air traffic capacity. While ATL operates predominantly under Visual Meteorological Conditions

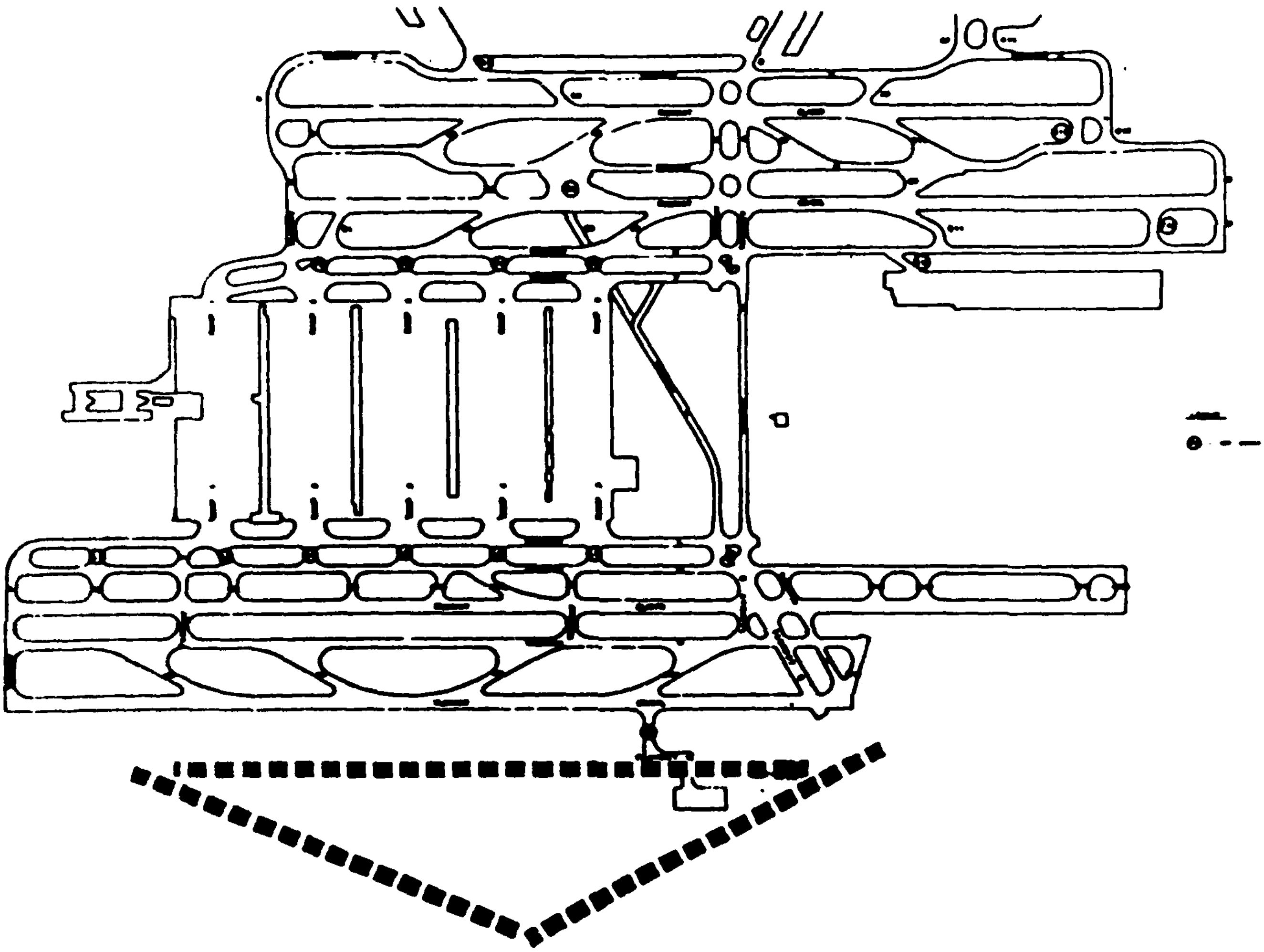

FIGURE 2. PROPOSED ATL CONFIGURATION (ATL TOWER PROPOSAL)

(VMC), if the increased operational capacity, which would be afforded by the new runway(s), was required to divert to the primary runways during the 8 percent of the time when conditions are between VFR and Category II (commuter aircraft currently do not operate into ATL below Category II), the resultant delays would certainly prove to be unacceptable to both passengers and operators. Since simultaneous triple IFR operations are not now authorized, no procedures and/or standards currently exist for such operations. Therefore, the Atlanta Committee requested FAA Headquarters to assist it in the runway selection decision process by developing and testing the requirements for low-minimum, triple IFR requirements and procedures and also for assistance in their implementation.

In July 1988, a report (prepared by The MITRE Corporation under the direction of the FAA's Advanced Concepts Division, AES-300) provided a detailed analytic review of ATL's enhancement alternatives. This study, using FAA Order 7110.98 (which governs Simultaneous Converging Instrument Approaches), the U. S. Standard for Terminal Instrument Procedures (TERPS), and validated current standard practice as references, provided a detailed, analytic evaluation of the impact of the Committee's proposed enhancements as well as a number of configurations and procedural options that had not been previously considered. Among these were the introduction of dependent operations to the parallel runways and the use of offset approach paths.

In the case of the offset approaches, a Localizer-Type Directional Aid (LDA) would be aligned so as to provide approach guidance along a path which is separated from that of the existing runways by at least the currently accepted minimum for independent IFR operations (4300 feet). At decision height (DH), if the runway was in sight, the incoming aircraft would S-turn into landing position if approaching a parallel runway, while one making an approach to a converging runway would make only a single turn to align with the centerline. The slower speeds and maneuverability of commuter aircraft would serve to facilitate the use of such procedures. The MITRE study concluded that dependent operation of the southernmost main runway and the commuter runway (with independent operation of the second main runway) could, indeed, provide maintenance of separation and adequate protection against a rapid and unpredicted course deviation (blunder) by one of the approaching aircraft, even with only 3000 feet of separation between the two southern runways. However, MITRE judged this alternative to have only limited utility since maintenance of the required 2-mile diagonal separation between aircraft on the adjacent runways would mean that this alternative could offer only a minimal increase in airport capacity during IFR operations.

This situation would be made even worse if dependent procedures were to be applied in the Atlanta situation, since the dependent operations would require synchronization of the relatively slow commuter traffic, which would be using the new runway, with the faster jet traffic on approach to the existing main runway. The study further concluded that, if an enhanced, rapid update rate, high resolution, radar (such as the 1-second update, high accuracy, phased array system which is currently under evaluation at Raleigh-Durham) were to be installed, independent commuter aircraft operations could be sustained to a third parallel runway, separated from 9R/27L by as little as 3500 feet, down to that runway's rated ILS Category.

In an attempt to provide the Southern Region, the Atlanta Tower, and the committee with additional information which they might use in their adoption of an airport modification(s) plan, the FAA Technical Center was requested to conduct a dynamic Air Traffic Control simulation of selected ATL enhancement alternatives. On July 20, 1988, Mr. Jeff Griffith, FAA, representing the Atlanta area, helped finalize the conditions which were to be simulated. The primary purpose of the agreed upon simulation was to give personnel from the Atlanta facility an opportunity to evaluate, using real-time dynamic simulation, potential modifications in the current TERPS covering converging runway operations and to reexamine the FAA Air Traffic Handbook standards for the use of closely spaced parallel runways as they would be applied within the context of the Atlanta proposals. More detailed objectives were to:

1. Assess the impact of reduced spacing between the existing and the proposed commuter parallel upon the ability of the air traffic controllers to detect and resolve potential conflicts during simultaneous independent approaches to three parallel runways.

2. Determine the ability of air traffic controllers to handle independent approaches to converging runways, to detect and resolve potential conflicts, and protect the No Transgression Zone (NTZ) during missed approach(s).

3. Confirm, to the extent possible, the increase in capacity of Atlanta's Hartsfield International Airport which was predicted to be the result of the addition of the commuter aircraft runway(s).

METHODOLOGY

The ATC Simulation, which was conducted at the FAA Technical Center, was designed and conducted in accord with the following:

SIMULATION FACILITY.

At the FAA's Technical Center, ATC simulations are run using the National Airspace Simulation Support Facility (NSSF). Physically, the NSSF consists of two SEL computers, the simulator pilot complex, and the main ATC Laboratory with the controller displays. The NSSF permits real-time, interactive simulation of en route and terminal airspace. It can be configured to match a facility's current operations by emulating existing traffic densities and mixes, radars, navigational aids, video maps, and communications. It has the further ability to examine proposed changes: different routes and procedures, additional runways, modification of separation standards, additional traffic demands, and new technology (new radars, MLS, modified displays, automated alerts, etc.).

Normally, participating controllers work in the ATC Laboratory (see figure 3) which has eight digital displays, with their associated keyboard data entry and communication equipment, which are similar to, but not identical with, the standard Automated Radar Terminal System and en route plan view displays (PVD's), consoles, and keyboards (see figure 4).

The ATC Laboratory is configured so that the subject controllers can function in a manner that is as close as possible to the way in which they would operate in the actual environment. Full controller-to-controller, controller-to-pilot (simulator operator), and pilot-to-controller communications are available for normal use. The ATC Laboratory is currently limited to six active displays and/or control positions, and up to two "ghost" positions which are used to control background and/or preprogrammed traffic. A maximum of 55 aircraft can be controlled at any given time. When larger simulations are needed, the airspace is divided into smaller configurations of the positions of interest and each position is studied in isolation. Maps and routes with display information based upon either present or proposed operations are used for simulated sectors and their displays. Patch-in telephone communications and computer linking serve to simulate sector operation in a realistic fashion. Where available, an analysis of the subject facility's past flight strips serves to ensure an appropriate mix of aircraft, routes, and identifiers.

The Simulator Pilot Complex (figure 5) houses the simulation pilots (operators) and their aircraft control consoles. The simulator operators are voice-linked with the controllers in the ATC Laboratory and convert their traffic control directives into keyboard entries to initiate the required computer simulation of the desired aircraft response. All aircraft responses are modifiable and are programmed to be consistent with the type of

FAA TECHNICAL CENTER ATLANTIC CITY, NEW JERSEY 89-0911

FIGURE 3. NSSF CONTROL AREA


FAA TECHNICAL CENTER ATLANTIC CITY, NEW JERSEY 89-0870

FIGURE 4. SIMULATED CONTROLLER POSITION

FAA TECHNICAL CENTER ATLANTIC CITY NEW JERSEY 89-0871

FIGURE 5. SIMULATOR PILOT COMPLEX

aircraft which is being simulated. The "pilots" also initiate communications to the controllers in the ATC Laboratory and provide them with any required procedural reports, emergency notifications, etc.

The analyses of NSSF based simulations typically rest upon:

1. Observations and judgments of the ATC specialists using the system as gathered through questionnaires, debriefings, and group discussions.

2. An analysis of the second-by-second computer records of each aircraft's position and altitude, recordings of pilot and controller actions, and selected quantitative statistics reflecting safety, work load, capacity, delays, etc.

3. Observations of supervisors and system planners made during the course of the simulation.

SIMULATION DESCRIPTION.

The potential hazards associated with operations involving any of the ATL runway options which might be selected may be classed under the headings of "blunders" and missed approaches. A blunder is defined as an unauthorized, unexpected turn toward a parallel approach path by an aircraft that, prior to the deviation, had been established on the localizer to its designated runway. While blunders can occur with any runway configuration, they have a special significance for ATL operations. The consideration of a parallel runway separation as low as 3000 feet will, compared to the standard minimum of 4300 feet, provide the approach monitor(s) with less time to detect the onset of a blunder, determine an appropriate corrective action, and successfully achieve the traffic adjustments necessary to resolve any potential conflict(s). In addition, ATL's proposed use of triple IFR operations means that a blunder toward the center of the runway system by an aircraft on either of the outside approach paths could potentially threaten, not just one, but two other approach operations. Also, when more than two runways are involved, any defensive actions initiated to resolve a conflict between one pair of aircraft have the potential to cascade into an interference situation with the third approach path. The simulation(s) conducted by the FAA Technical Center to assist the city of Atlanta in its selection of the most cost effective airport enhancement option were as follows:

RUNWAY REPLACEMENT. Two prospective additions were evaluated. The first was the addition of a parallel commuter runway, 5500 feet in length, positioned 3000 feet south of the existing 9R/27L. The threshold of this new runway, designated "runway 10," was approximately 6000 feet east of the threshold of 9R (figure 6). The second runway placement evaluated was a diagonal runway, designated "Runway 6," which was also 5500 feet in length and was positioned as shown in figure 7. This runway represented one of the pair of diagonal runways which had been proposed. The second diagonal runway was not digitally formatted since only operations from west to east were included in the current simulation.

CONFIGURATIONS. The simulation was divided into a series of configurations that could be accommodated by the NSSF. These were:

1. Feeder Baseline - Existing traffic with commuters from all four arrival fixes (DALLAS, LOGEN, TIROE, and HUSKY (see figure 8) landing on runways 8L and 9R.

2. Feeder "Trips" - Using a three (triple) parallel runway configuration, jets and large four-engine props were vectored to land on runways 8L and 9R. Commuters from DALLAS and LOGEN land on runway 8L with some pulled to runway 9R. Commuters from TIROE and HUSKY were vectored to land on runway 10 with some pulled to runway 9R (figure 8).

3. Feeder Converging - Jets and large four-engine props were vectored to land on runways 8L and 9R. Commuters from DALLAS and LOGEN land on runway 8L with some pulled to runway 9R. Commuters from TIROE and HUSKY were vectored to land on runway 6 with some pulled to runway 9R (figure 9).

4. Monitor "Trips" - Monitor the approach traffic that was set up in the Feeder "Trips" (three parallel runways) configuration.

5. Monitor Converging - Monitor the traffic that was set up in the Feeder Converging configuration.

PILOT ERRORS AND BLUNDERS. Special scenarios of scripted "blunders" were prepared. These scripts provided for generation of blunders in accord with the following rules:

1. A time for the initiation of each blunder was selected from a sample of random intervals between blunders which had a mean of 3 minutes and minimum and maximum intervals of 1 and 5, respectively.

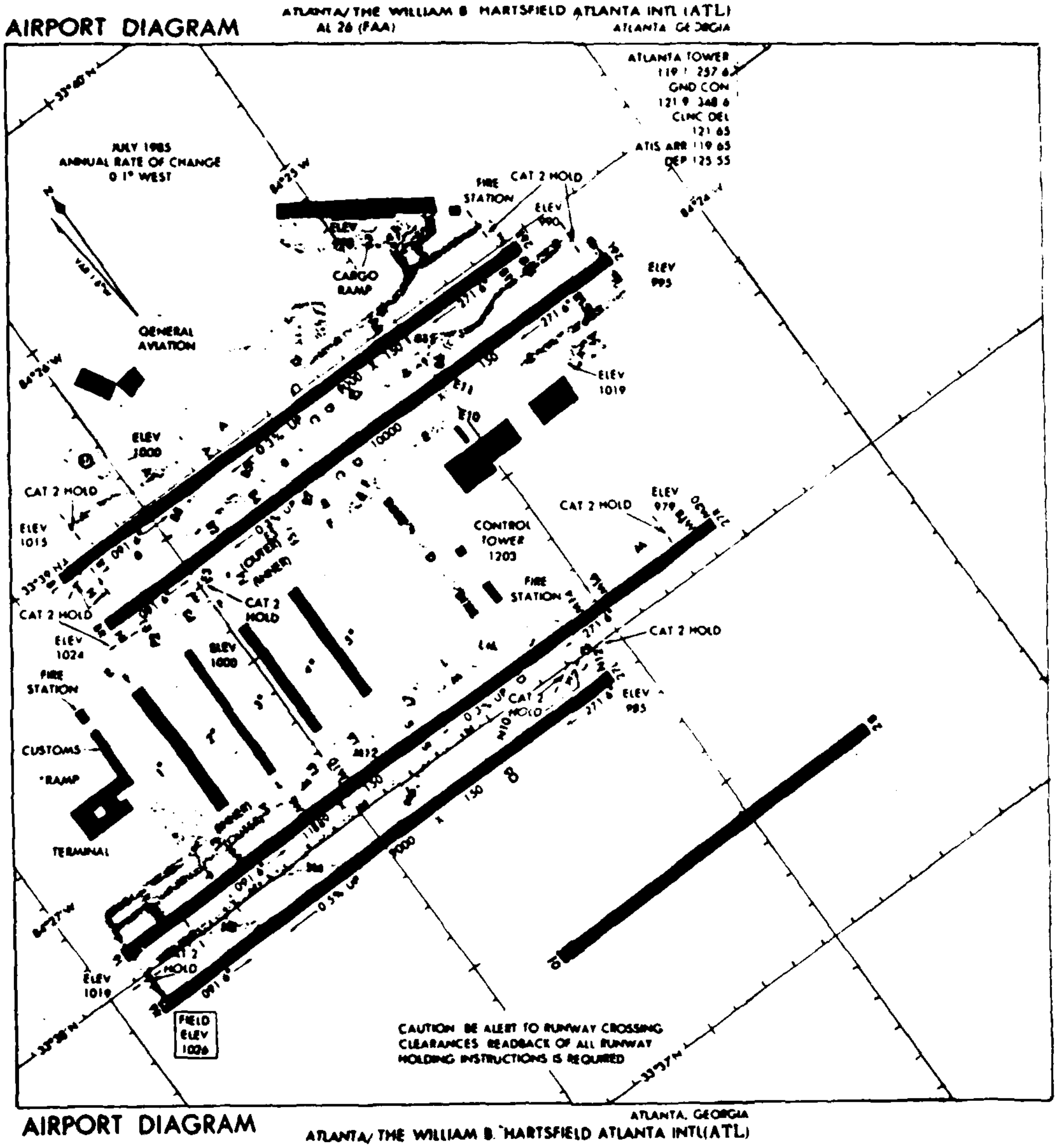

FIGURE 6. PROPOSED THIRD PARALLEL RUNWAY 10/28
(3000-FOOT SEPARATION)

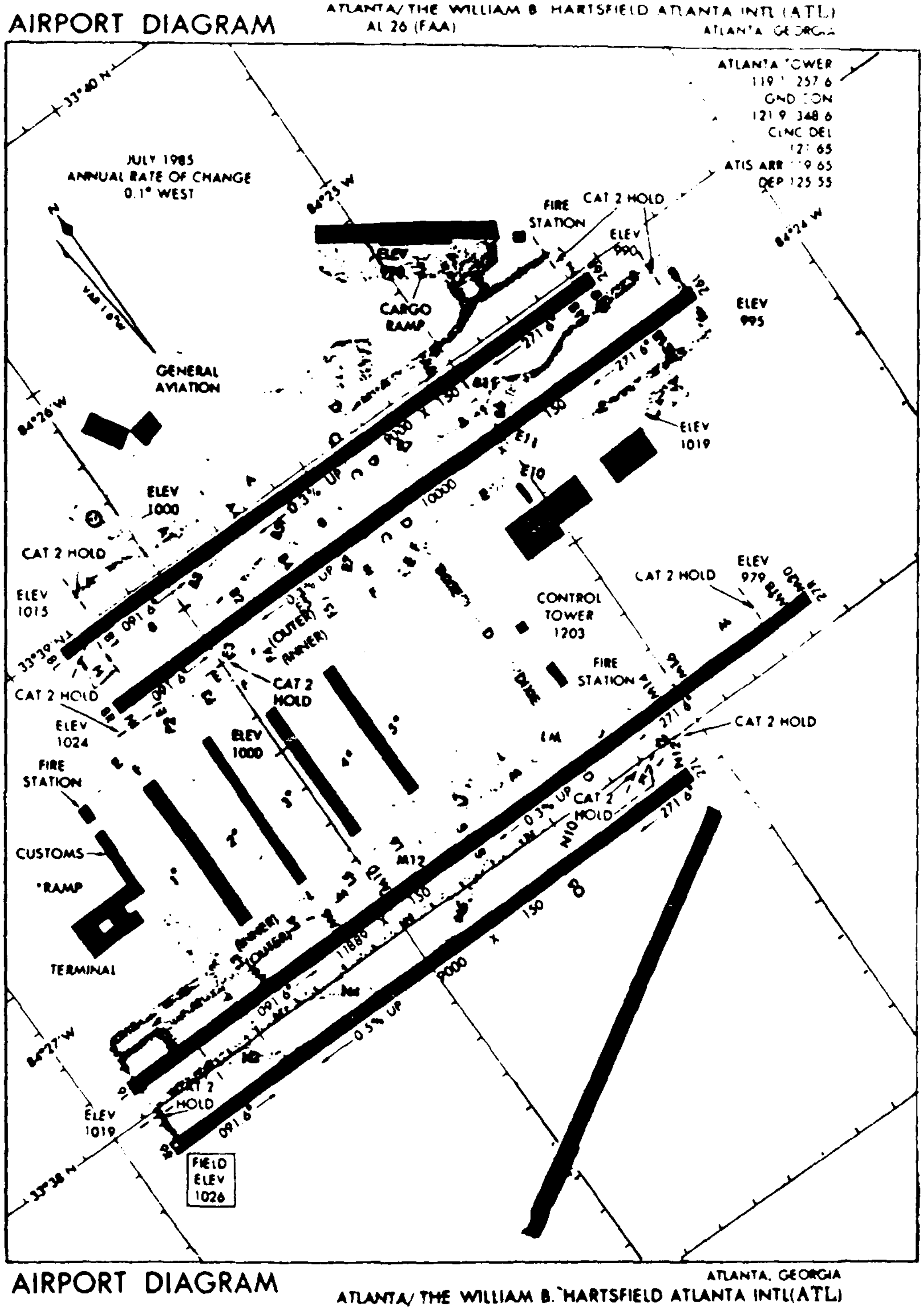

FIGURE 7. PLACEMENT OF THE PROPOSED CONVERGING RUNWAY 6

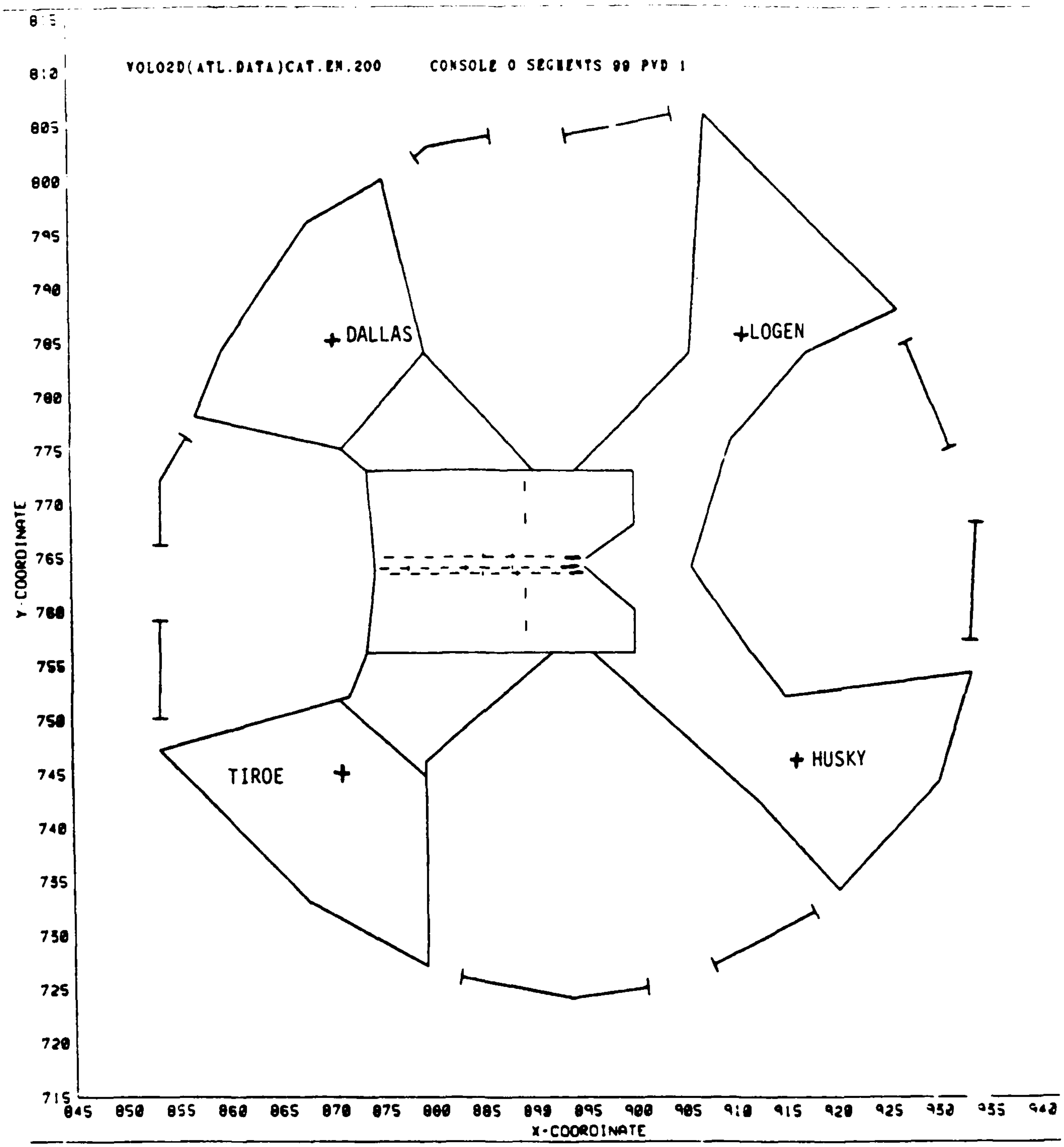

FIGURE 8. CONFIGURATION USED FOR FEEDER TAPES AND THIRD PARALLEL TRAFFIC MANAGEMENT

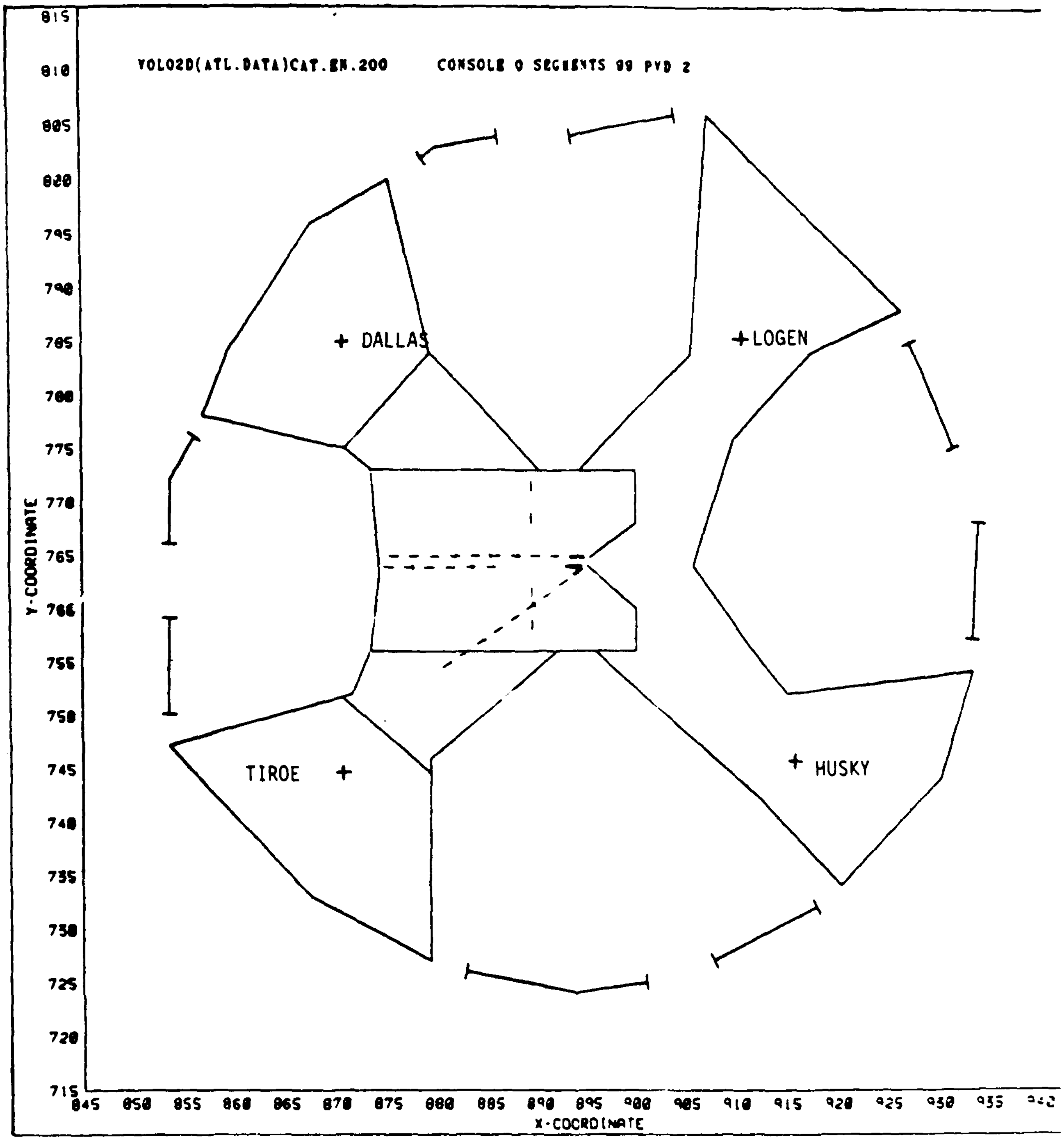

FIGURE 9. CONFIGURATION USED FOR CONVERGING RUNWAY TRAFFIC MANAGEMENT

2. The runway flightpath of the blundering aircraft was selected at random from the three being used such that each had an equal probability of selection.

3. An aircraft was randomly selected, counting the last aircraft in the sequence as No. 1, the one in front of that as No. 2, and so on, with numbers 1, 2, 3, and 4 having equal probabilities.

4. The direction of turn for the blunder was chosen so that aircraft on outside runways always turned toward traffic, while aircraft on the inside had an equal chance of going to the right or to the left.

5. The size of each blunder was chosen so that the blundering turn had a 60 percent chance of being 30 degrees, a 20 percent chance of being 20 degrees, and 20 percent of being 10 degrees.

6. A decision was made for each blundering aircraft as to whether the pilot would respond to further clearances after the blunder had been initiated. The probability of such a "communications failure" was 40 percent for the Atlanta simulation.

7. For general analysis, each blunder was required to be independent, i.e., not confounded with another blundering aircraft. Any blunders which began within 61 seconds of the beginning of a previous blunder were considered "simultaneous" and the control problems posed by both aircraft were extracted from the general data base and subjected to separate analysis.

SPECIAL FEATURES. The Atlanta simulation incorporated a number of special safety features into the parallel approach monitor's positions:

1. A 1-second update rate, high accuracy radar was used. This radar was modeled after the "Phased Array" system currently undergoing evaluation at Raleigh-Durham.

2. An automated alerting system was used. This alert caused the tag of any aircraft which entered the NTZ to blink. Slewing the cursor to the target and pressing <enter> caused the tag to stop blinking.

3. Display scale expansion was used to increase the controller's awareness of the Normal Operating Zone (NOZ) and the NTZ boundaries. It also made navigational errors more apparent. Display expansion was accomplished by expanding the scale by a factor of 2 normal to the ILS, doubling the displayed distance between the ILS's while leaving the longitudinal scale unchanged.

SCOPE SET-UPS. The following scope assignments were utilized for the Atlanta Simulations within the ATC Laboratory:

1. Scope set-up for feeder baseline and feeder trips (figure 10):

Scope	H	A	V	D
Controller	South	South	North	North
Position	Feeder	Final	Final	Feeder
Frequency	127.9	118.35	127.25	126.9

2. Scope set-up for feeder converging (see figure 11):

Scope	H	X	A	V	D
Controller	South	SAT	South	North	North
Position	Feeder	Final	Final	Final	Feeder
Frequency	127.9	11:65	127.25	126.2	126.9

3. Scope set-up for feeder/trips and converging monitoring (see figure 12):

Scope	X	A	V
Controller	Runway	Runway	Runway
Position	10 or 6	9R	8L
Frequency	123.95	119.1	119.5

ANALYSIS

METHOD.

The primary method of analysis used to evaluate the Atlanta Simulation data was a detailed review of the time-indexed plots of the ground tracks of the aircraft involved in the traffic control problems. Figure 13 is a representative sample of these plots. In order to reduce clutter on these plots, the time scale, represented by the sequential numbers appearing next to each ground track, was modified to be displayed in seconds since run initiation divided by ten. Thus, in the sample plot shown in figure 13, the plots began at time hack 113, which is 1130 seconds (or just under 19 minutes) after the run began. The

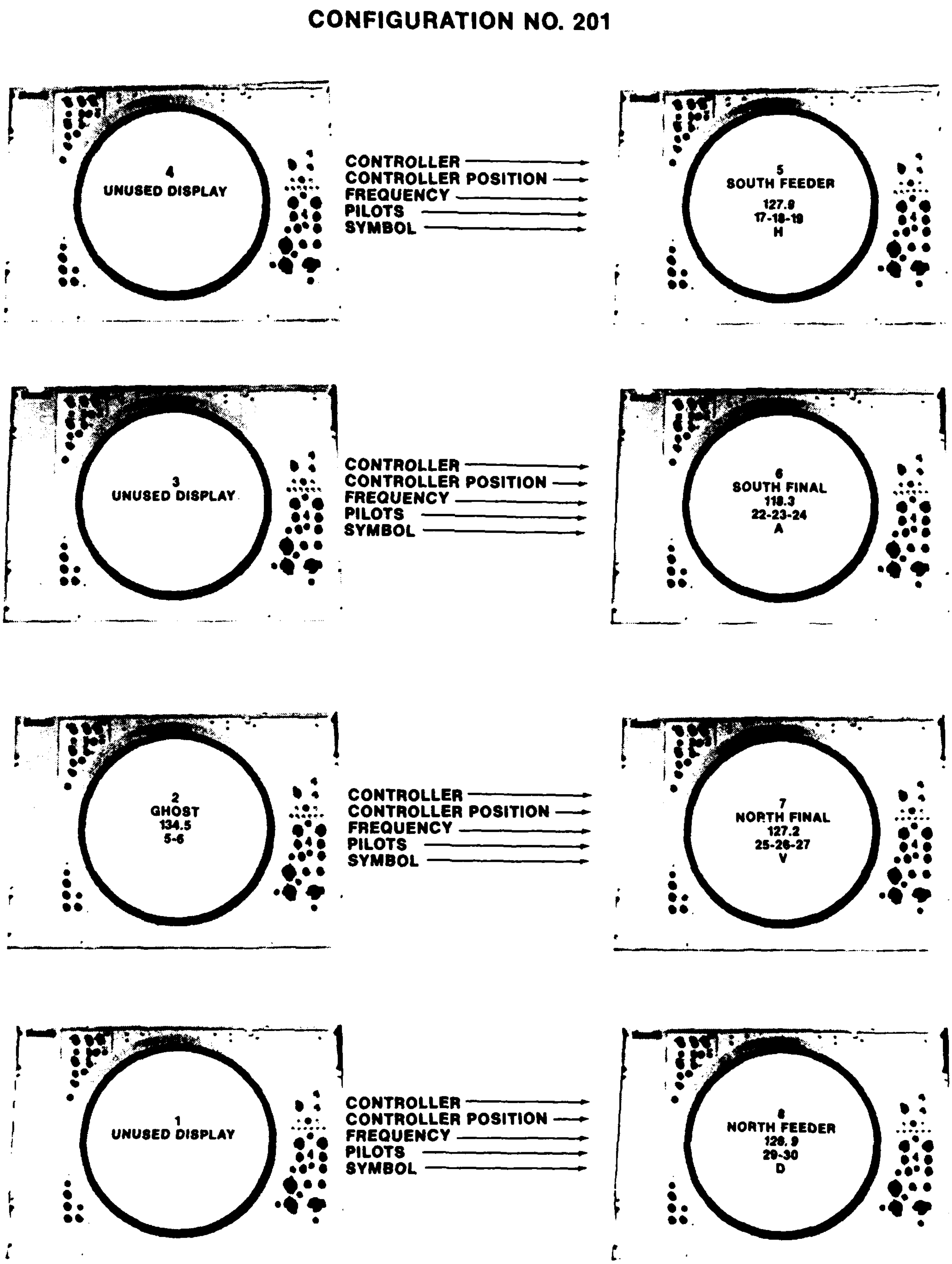

FIGURE 10. SCOPE CONFIGURATION FOR FEEDER BASELINE AND FEEDER TRIP SIMULATION RUNS

CONFIGURATION NO. 202 AND 203

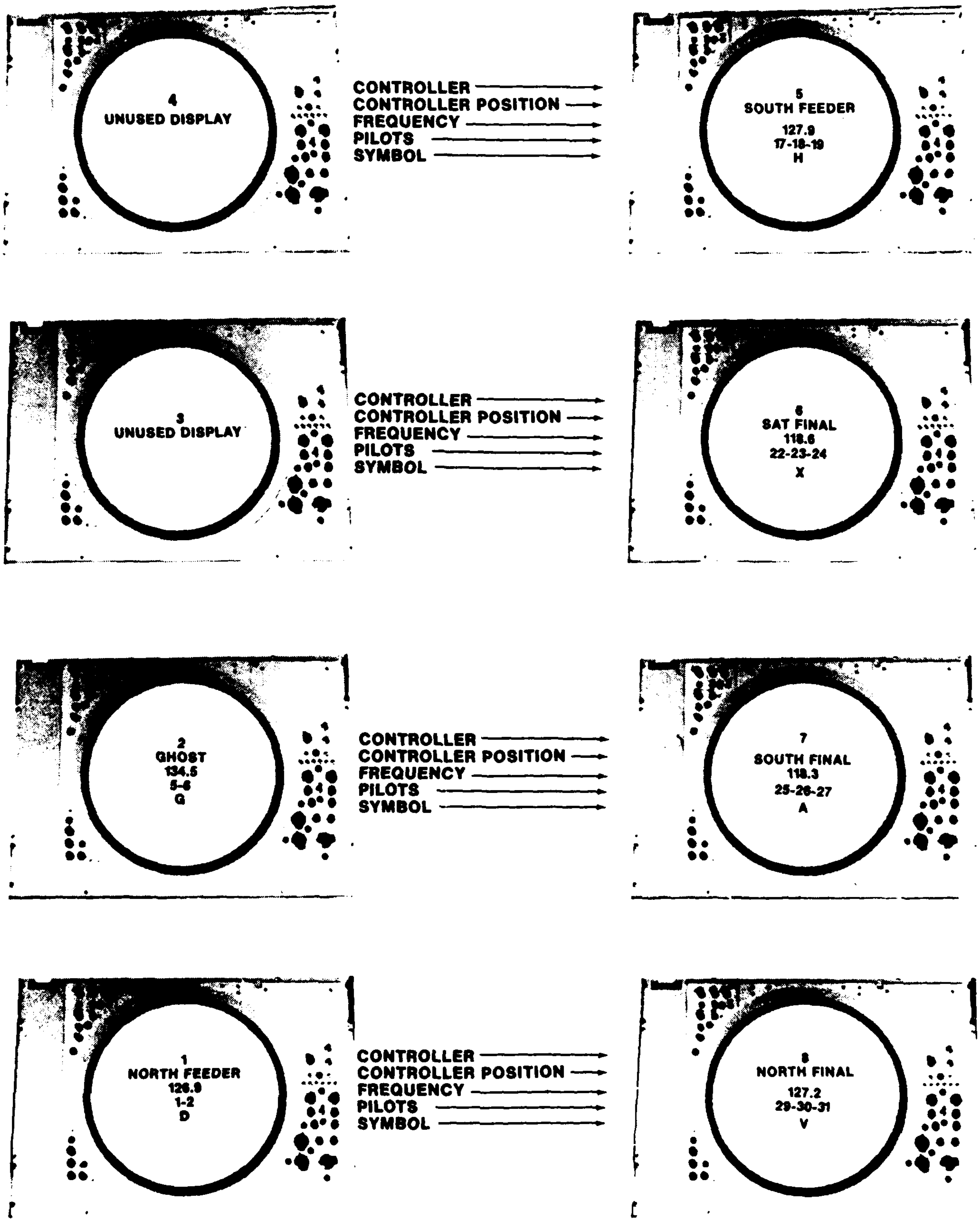

FIGURE 11. SCOPE CONFIGURATION FOR FEEDER CONVERGING SIMULATIONS

CONFIGURATION NO. 204 AND 205

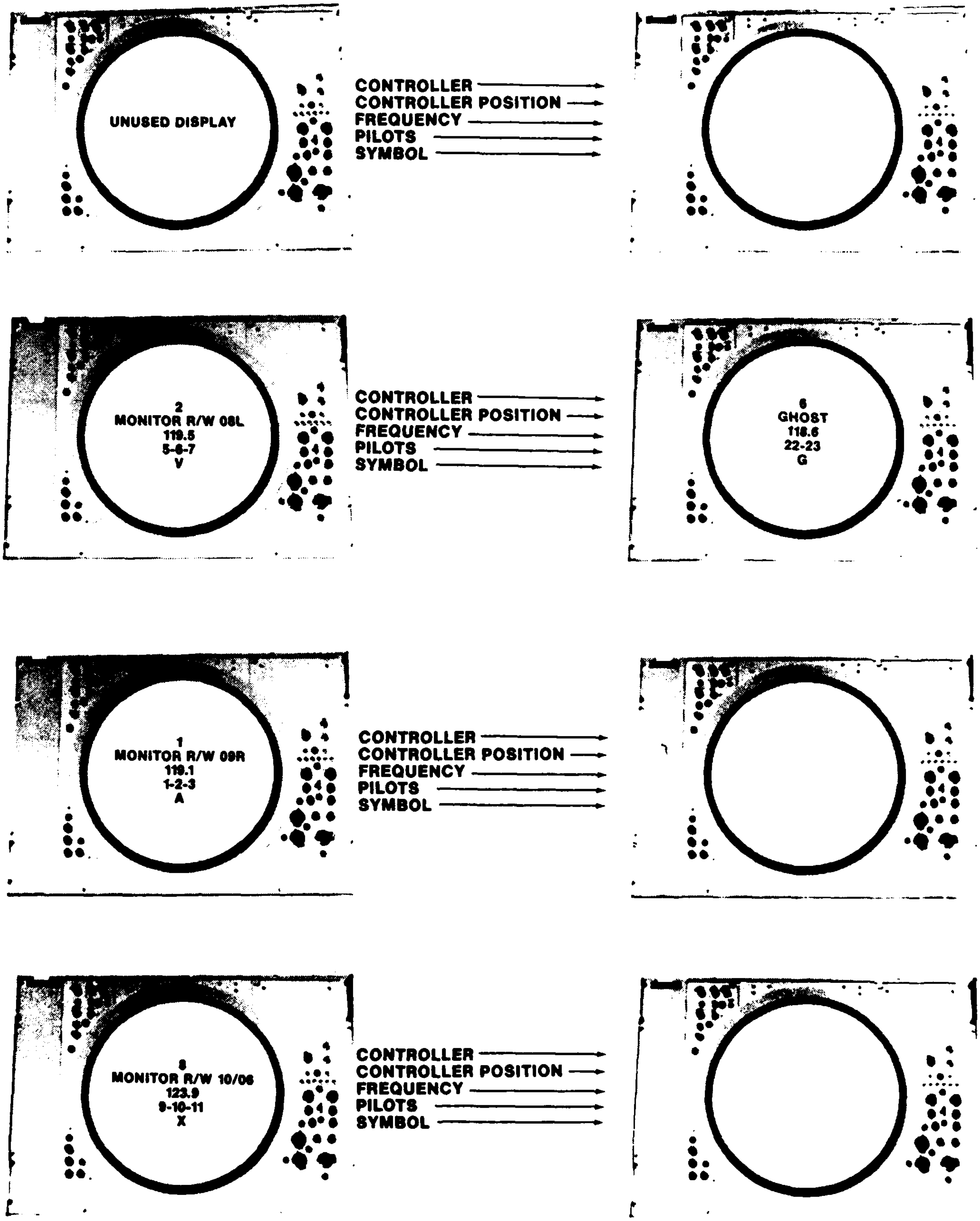

FIGURE 12. SCOPE CONFIGURATION FOR PARALLEL AND CONVERGING MONITORING SIMULATION RUNS

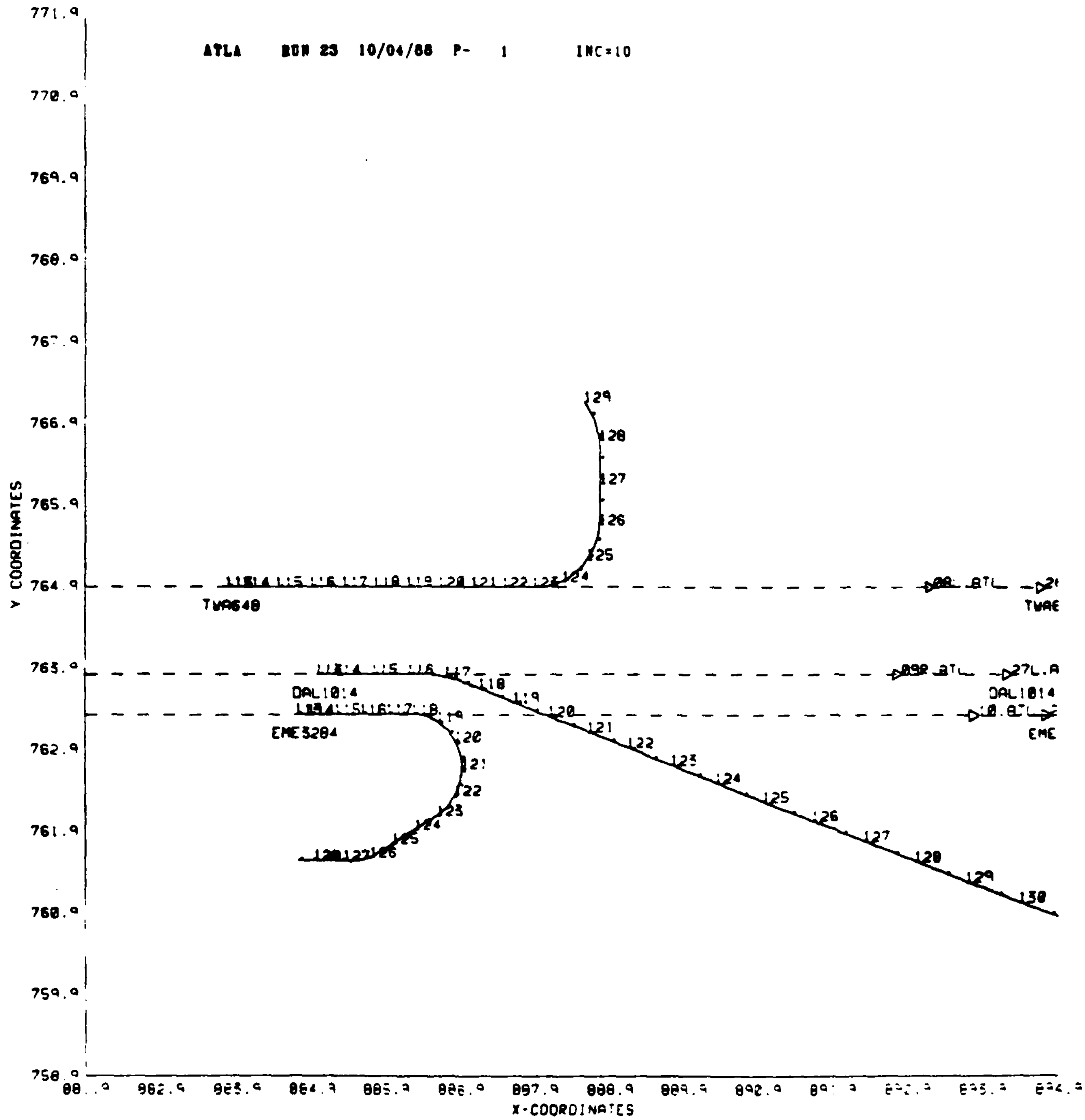

FIGURE 13. REPRESENTATIVE SAMPLE OF ATLANTA SIMULATION PLOTS

graphic information contained in these plots was augmented by summary sheets of numeric data (see figure 14) which show altitude and speed data for each of the aircraft involved in a conflict, or potential conflict, situation. The plots are linked to the start of a "blunder," the time scales are adjusted to show what was happening for 30 seconds before the blunder was initiated, and continue for an additional 150 seconds after the onset of the blunder. In addition, printouts were generated of all responses which the "pilots" made in reaction to controller communications (see figure 15). Detailed, second-by-second digital printouts of these data were available, if needed, to resolve any uncertainties about what actually happened during a problem. The track codes used to annotate the aircraft activities associated with these data are summarized in table 1.

The data obtained during the approaches to the parallel runways were grouped into a four-way summary matrix (see figure 16) which broke the data into: (1) blunders which impacted runways separated by the current distance (runways 8L and 9R), labelled as "existing;" and (2) those which directly involved the 3000-foot separation runway, runway 10, labelled as "proposed." The data were further broken down into those blunders which were a potential threat to only one other runway localizer path (e.g., a left or right turn off of 9R) and those which had the potential to impact two runways (e.g., a left turn from runway 10 or a right turn from runway 8L). The blunders which initially involved the existing runway separations could, thus, serve as a baseline for the comparative evaluation of those situations which involved the reduced separation.

METRICS.

In addition to the graphic data plots, several new quantitative measures, or metrics, were utilized to enhance the understanding of both the severity of the traffic control problems posed during the simulation and the ability of the controllers to resolve them in a timely and effective fashion. The first of these measures used was the Aircraft Proximity Index (API). This index represents a weighted measure of the potential hazard associated with combinations of lateral and vertical separation. A three-dimensional representation of this weighted index is shown in figure 17. Computation of the API is described in appendix A. While the API can provide very useful information, it is not affected by the relative motions of the aircraft involved, but reflects only their separation. Therefore, to provide additional quantitative information on the Atlanta ATC simulation outcome, a vector based measure, the Projected Closest Point of Approach (PCPA) was developed. This index, which is mathematically defined in appendix B of this report, provides a second-by-second

DATE OF RUN 10/04/88 RUN - 23 PLOT- 1

DAL1014 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
113	1134	885.042	763.923	3797.	1060	.00
114	1139	885.291	763.923	3709.	1060	.25
115	1149	885.787	763.923	3534.	1060	.74
116	1159	886.282	763.923	3358.	1060	1.24
117	1169	886.774	763.892	3183.	1000	1.73
118	1179	887.244	763.750	3038.	1000	2.23
119	1189	887.709	763.583	2894.	1000	2.72
120	1199	888.192	763.408	3224.	1000	3.23
121	1209	888.702	763.224	3641.	1000	3.78
122	1219	889.245	763.028	3998.	1000	4.35
123	1229	889.826	762.818	4000.	1000	4.97
124	1239	890.434	762.598	4000.	1000	5.62
125	1249	891.070	762.368	4000.	1000	6.29
126	1259	891.734	762.128	4000.	1000	7.00
127	1269	892.421	761.880	4000.	1000	7.73
128	1279	893.112	761.631	4000.	1000	8.46
129	1289	893.803	761.382	4000.	1000	9.20
130	1299	894.494	761.133	4000.	1000	9.93
131	1309	895.185	760.884	4000.	1000	10.67

EME3284 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
113	1134	884.768	763.431	3905.	1060	.00
114	1139	884.944	763.431	3850.	1060	.18
115	1149	885.295	763.431	3739.	1060	.53
116	1159	885.646	763.431	3628.	1060	.88
117	1169	885.995	763.431	3517.	1060	1.23
118	1179	886.344	763.431	3407.	1060	1.58
119	1189	886.678	763.342	3297.	1000	1.93
120	1199	886.921	763.098	3187.	1000	2.27
121	1209	887.010	762.766	3076.	1000	2.62
122	1219	886.921	762.435	2966.	1000	2.97
123	1229	886.679	762.193	2856.	1000	3.32
124	1239	886.378	762.020	2746.	1000	3.66
125	1249	886.079	761.847	2636.	1000	4.01
126	1259	885.777	761.680	2543.	1000	4.35
127	1269	885.418	761.635	2805.	1000	4.72
128	1279	885.022	761.635	3138.	1000	5.11

FIGURE 14. NUMERIC DATA SAMPLE

ATLANTA

RUN: 23   SAMPLE: 904/204   RUN-DATE/TIME: 10/04/88   8:32:1

P I L O T   M E S S A G E S :

TIME	ACTION	RWY1	IDENT1	TDST1	HDG1	SPD1	ALT1	TRACK	MESSAGE:
00:01:18	CLEARED	09R	PAA556	.00	90.	186.	6000.	1	ILSA 09 R
00:02:11	CLEARED	09R	AAL1015	.00	90.	0.	6000.	1	ILSA 09 R
00:03:42	CLEARED	09R	DAL9982	.00	90.	186.	6000.	1060	ILSA 09 R
00:04:26	INFORM	10.	ASE260	.00	90.	167.	4000.	1	DISP 713
00:05:04	CLEARED	09R	DAL687	.00	90.	190.	5994.	1060	ILSA 09 R
00:05:11	INFORM	10.	ASE260	.00	90.	167.	4000.	1	DISP 713
00:05:23	VECTOR	10.	ASE211	.00	93.	167.	4000.	1000	RITE
00:05:42	VECTOR	10.	ASE211	.00	144.	167.	4000.	1000	LEFT HDG 070
00:06:12	VECTOR	10.	ASE260	.00	92.	167.	4000.	1066	RITE 10 JNIC MODE L MODE 10
00:06:26	ALTITUDE	10.	ASE211	.00	70.	167.	3994.	1000	DSCN 30
00:06:33	CLEARED	10.	ASE211	.00	70.	167.	3810.	1000	ILSA 10
00:07:04	INFORM	08L	AAL802	.00	81.	186.	5000.	1000	FIX FIX FIX LEFT HDG 360
00:07:07	CLEARED	09R	DAL114	.00	90.	190.	6000.	1060	ILSA 09 R
00:07:41	CLEARED	08L	EAL265	7.89	90.	189.	5000.	1060	ILSA 08 L
00:07:46	CLEARED	08L	DAL1906	11.99	90.	186.	5000.	1060	ILSA 08 L
00:07:51	CLEARED	10.	ASE260	10.46	90.	167.	3994.	1060	ILSA 10
00:07:51	CLEARED	08L	USA571	15.76	90.	189.	5000.	1060	ILSA 08 L
00:07:58	VECTOR	08L	AAL802	.00	357.	186.	5000.	1000	LEFT HDG 270
00:08:03	CLEARED	10.	N456CS	14.07	90.	167.	4000.	1060	ILSA 10
00:08:19	CLEARED	10.	AA03324	17.40	90.	170.	4000.	1060	ILSA 10
00:08:28	CLEARED	08L	DAL125	18.07	90.	187.	5000.	1060	ILSA 08 L
00:09:02	SPEED	10.	ASE260	7.21	90.	154.	3277.	1060	SPD 120
00:09:05	CLEARED	09R	DAL499	.00	90.	185.	6000.	1060	ILSA 09 R
00:09:11	CANCEL	08L	AAL802	.00	270.	186.	5000.	1000	CNCL
00:09:41	CLEARED	10.	ASE320	17.88	90.	167.	4000.	1060	ILSA 10
00:10:06	CLEARED	09R	DAL616	.00	90.	186.	6000.	1	ILSA 09 R
00:10:19	MISSED	08L	EAL265	.96	90.	143.	1429.	1100	DISTANCE FROM CENTER LINE: 0-L
00:10:44	CLEARED	08L	DAL1497	.00	90.	185.	4994.	1060	ILSA 08 L
00:10:45	CLEARED	10.	AA03360	.00	90.	167.	3994.	1060	ILSA 10
00:10:45	CLEARED	08L	DAL133	17.12	90.	189.	5000.	1060	ILSA 08 L
00:10:54	SPEED	10.	N456CS	6.18	90.	162.	2954.	1060	SPD 130
00:10:59	SPEED	10.	AA03324	9.87	90.	168.	3994.	1060	SPD 140
00:10:59	CLEARED	10.	ASE86	17.99	90.	180.	4000.	1060	ILSA 10
00:11:09	CANCEL	08L	EAL265	1.36	356.	198.	3159.	1101	CNCL
00:11:17	CLEARED	08L	ASE190	.00	90.	175.	5000.	1060	ILSA 08 L
00:11:42	CLEARED	09R	DAL83	.00	90.	192.	6000.	1060	ILSA 09 R
00:11:58	SPEED	10.	AA03324	7.38	90.	146.	3341.	1060	SPD 120
00:12:09	SPEED	10.	N456CS	3.28	90.	125.	2047.	1060	SPD 120
00:12:14	CLEARED	10.	ASE2	.00	90.	167.	4000.	1	ILSA 10
00:12:15	SPEED	10.	ASE86	14.19	90.	178.	3994.	1060	SPD 140
00:12:35	INFORM	10.	ASE86	13.34	90.	164.	3994.	1060	DISP 0
00:12:42	INFORM	10.	ASE86	12.94	90.	157.	3994.	1060	DISP 4

FIGURE 15. SAMPLE COMMUNICATIONS PRINTOUT

TABLE 1. ATL SIMULATION AIRCRAFT TRACK CODES

CODE		DEFINITION
1	=	ON-FLIGHT-PLAN
2	=	ON-FLIGHT-PLAN-TAKEOFF
1000	=	OFF-FLIGHT-PLAN-ON-VECTORS
1060	=	FLYING-ILS-APPR
1061	=	HOMING-TO-ILS-APPROACH
1062	=	FLYING-ILS-LOCALIZER
1063	=	HOMING-TO-ILS-LOCALIZER
1065	=	AT-ILS

CODE		DEFINITION
1066	=	FLYING-TO-ILS-INTERCEPT
1067	=	DRIFTING-FROM-ILS
1100	=	INITIATE-MISSED-APPR
1101	=	FLYING-MISSED-APPROACH
1102	=	AT-MAP--CHECK-IF-MISSED-APP
1200	=	INITIATE-LANDING-MANUEVER
1201	=	LANDING
1202	=	LANDING-TOUCHDOWN-DECELERAT

POTENTIAL
RUNWAYS THREATENED

	One Runway	Two Runways
Existing	9R - Turn R	8L - Turn R
Proposed	9R - Turn L	10L - Turn L

FIGURE16. ATLANTA SIMULATION DATA MATRIX

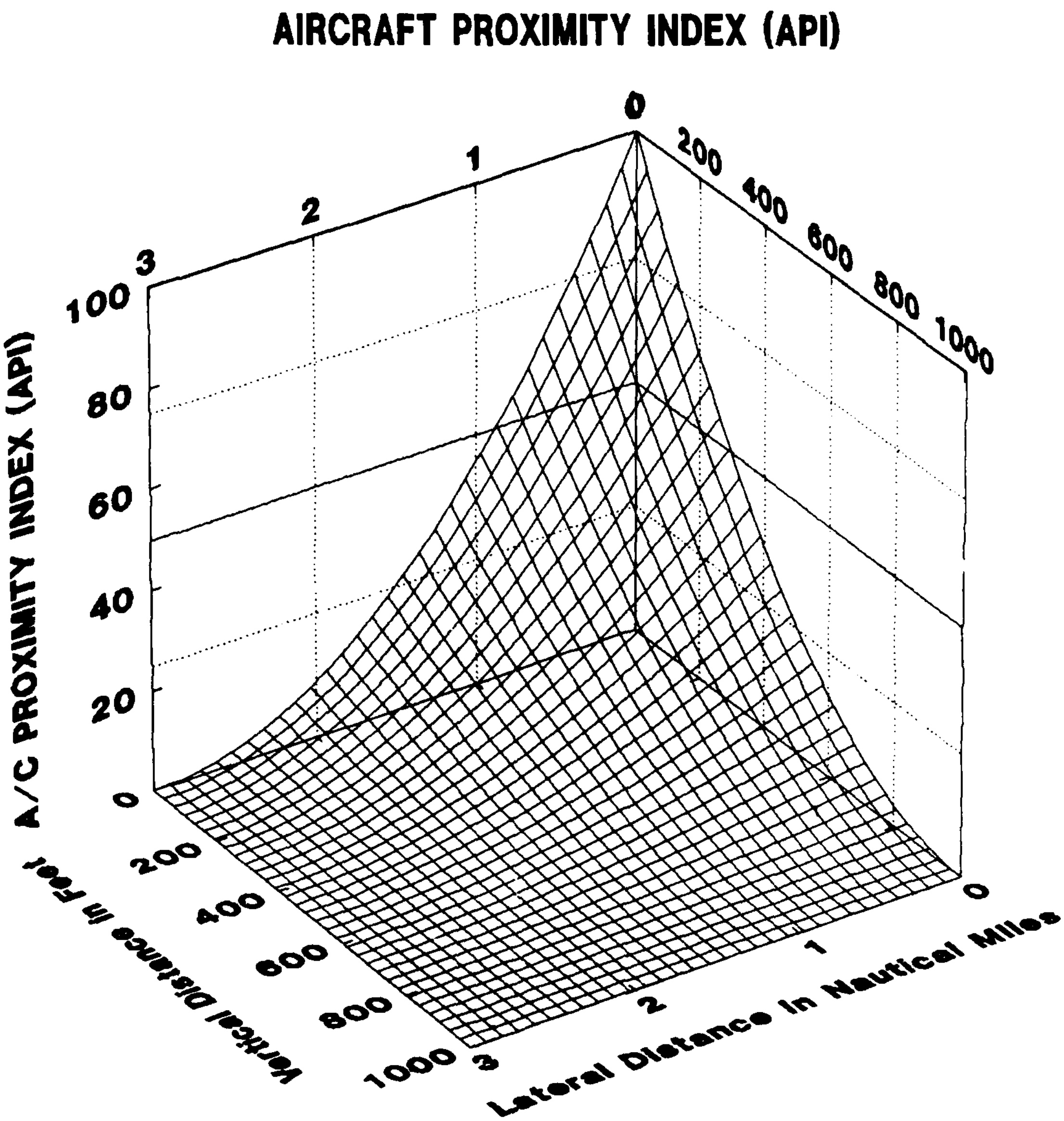

FIGURE 17. API INDEX AS A FUNCTION OF LATERAL AND VERTICAL SEPARATION

prediction of how close the subject aircraft will come to each other if nothing happens to change their current state. In addition, the PCPA calculations also provide a second-by-second measure of how long it will be until the PCP of Approach actually occurs; i.e., how long does the controller-pilot team have to achieve a resolution to the situation before it reaches its worst case point. These indices were plotted on the same time frame as that used for their corresponding graphic data plots (see figure 18).

At the completion of each data run, each subject controller completed the questionnaire shown in figure 19. These questionnaires were analyzed for each traffic configuration to access the controllers' subjective opinions regarding the challenge posed by the traffic problems and the realism of the simulation.

PROCEDURE.

The basic unit of analysis was initiated by an individual blunder and the subsequent time course of events in the airspace triggered by that blunder. For each blunder, all available data were examined to determine if a situation occurred which was or was not successfully handled by the controller, i.e., without incurring excessive risks to any of the involved aircraft. Data available for each run included the time-indexed track plots X, Y, and Z coordinates of each aircraft in the affected airspace as a function of time, time plots of API, Closest Point of Approach (Predicted), and time to reach closest point of approach, along with all controller communications and associated pilot action.

To isolate those situations that might pose an unacceptable hazard, a decision tree was developed which applied step-by-step decision rules to each set of blunder-generated conflicts. These rules are shown in figure 20.

First, if no involved aircraft were predicted to come within 0.5 nautical mile (nmi) slant range (about 3000 feet) of any other aircraft, the blunder was eliminated from further analysis. Note that the first three rules involved <u>predicted</u> values, that is, the momentary estimated outcomes if there is no further controller intervention. This is a conservative strategy that identifies whether or not the aircraft was under <u>potential</u> threat at any point.

Second, if PCPA was under 0.5 nmi, altitude separation at the time of PCPA was examined. If separation was greater than 500 feet, the blunder was dropped from analysis.

Third, if a possible threat was identified from the first two rules, the time remaining until PCPA would be reached was determined. This is the time available to a controller to

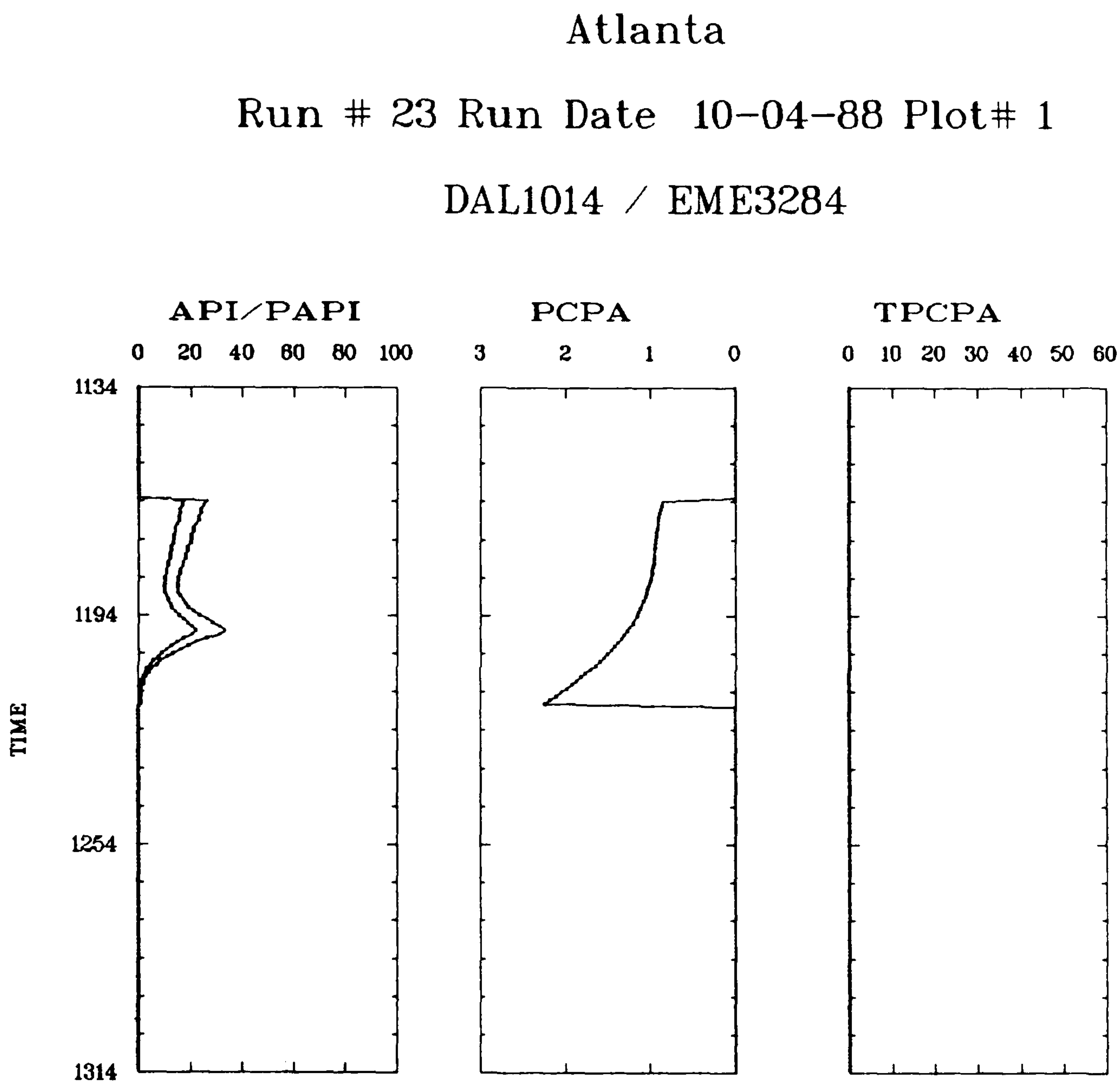

FIGURE 18. SAMPLE API AND PCPA PLOTS

QUESTIONNAIRE - ATLANTA SIMULATION

(One per controller per test session.)

Controller Code No:.____, Date:__ __-88, Start time__:__, Position:______

PLEASE FILL OUT THIS BRIEF QUESTIONNAIRE ON THE RUN YOU HAVE <u>JUST COMPLETED.</u>

1. Except for deliberately introduced incidents, how realistic did you feel this traffic?

0	1	2	3	4	5
VERY ARTIFICIAL					VERY REALISTIC

2. How hard to you feel you had to work on this run?

0	1	2	3	4	5
NOT HARD AT ALL					VERY HARD

3. How well do you feel you were able to control the traffic in this run, using this system?

0	1	2	3	4	5
CONTROL IS QUESTIONABLE					CONTROL IS GOOD

4. If the conditions of this run (volume of traffic, procedures, geography) were offered at your facility, how would you feel?

0	1	2	3	4	5
STRONGLY OPPOSE					STRONGLY FAVOR

<u>COMMENTS</u>:

FIGURE 19. ATL SIMULATIONS QUESTIONNAIRE

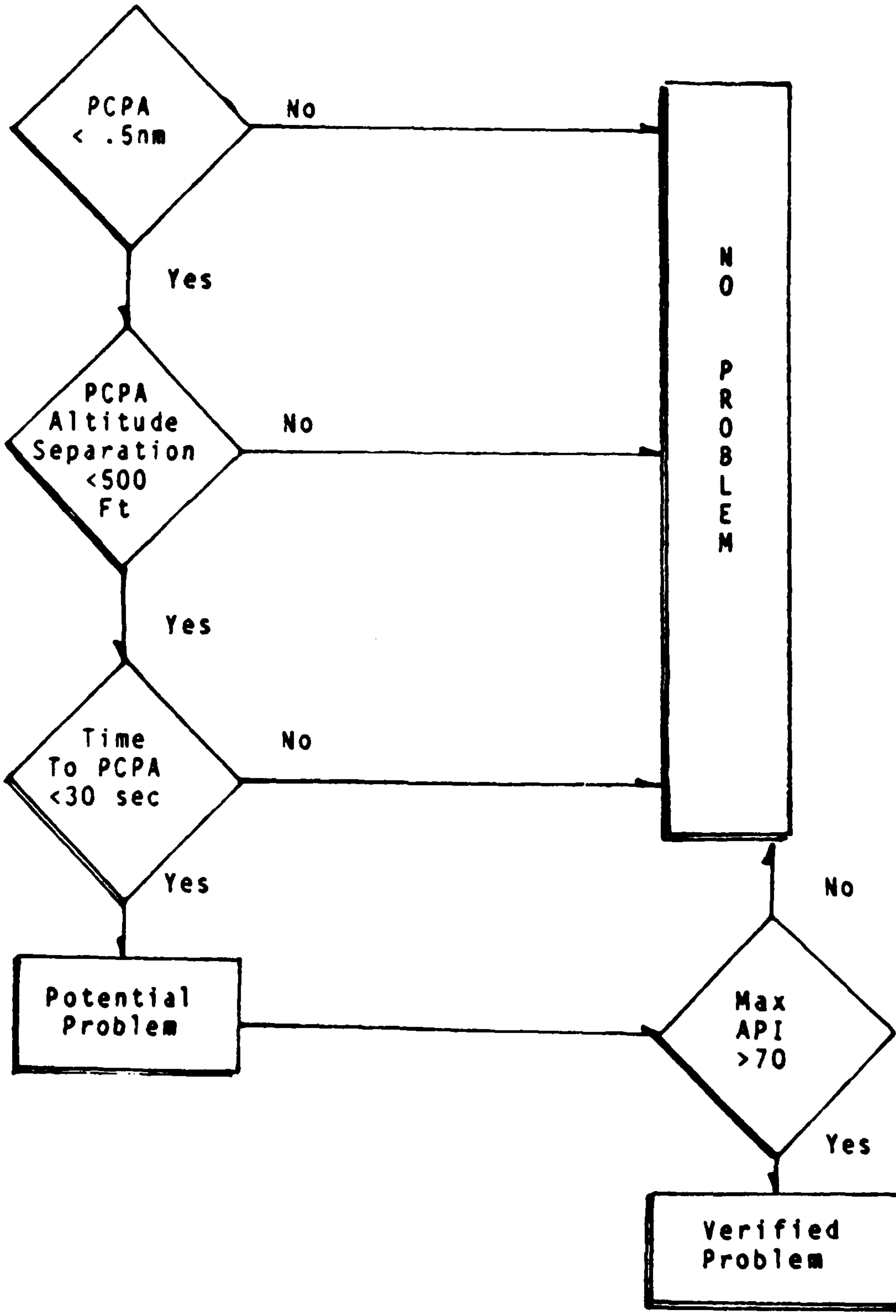

FIGURE 20. "PROBLEM" IDENTIFICATION RULES

intervene and change the system state. If more than 30 seconds remained to take action, the blunder was not classified as a problem.

The blunders remaining after application of the first three rules were defined as "potential problems," that is, there was at some time in the simulation a possibility that the aircraft would pass close together. Because these predictions of CPA and time to CPA were momentary estimates (constantly changing as the aircraft responded to controller intervention) it is possible for a blunder which shows a near-zero predicted CPA to result in an outcome in which the aircraft are never in any close proximity. Thus, the final rule applied involved the maximum value of the API obtained at any point during the event. If the maximum API was less than .70, the blunder was dropped. Otherwise, the blunder was classified as a "verified problem." For the verified problems, more detailed analyses were carried out to determine precise location of each involved aircraft throughout the event.

In addition to these visual, or graphic, analyses, a general linear model analysis of variance was performed on data from all conflicts, using maximum API as the dependent variable. Runway separation distance, the amount of excursion of the triggering blunder (10, 20, or 30 degrees), and the number of threatened runways served as the independent variables.

RESULTS

PARALLEL OPERATIONS.

IDENTIFICATION OF PROBLEM EVENTS. A total of 101 sets of time-track plots and associated index data were analyzed. Of these, 9 involved "multiple blunders," that is, blunders on more than one runway were initiated within 20 seconds of one another. These were judged to be so unrepresentative of actual operations that their inclusion would have biased the analysis results. They are addressed separately in a later section to illustrate the ability of controllers to handle extremely improbable, unusual events.

The remaining 92 sets are distributed across the summary matrix cells as shown in table 2. Since the simulation involved random introduction of blunders across time and across runways, the frequencies in each cell are not expected to be the same. Applying the decision rules in figure 19 resulted in the identification of 10 potential problems, of which 5 were verified problems. The distribution of identified problems across cells of the matrix and associated percentages of total are shown in table 3. About 5 percent of all blunder-initiated conflicts resulted in a verified problem as defined by the decision rules.

TABLE 2. DISTRIBUTION OF BLUNDER-RELATED DATA SETS IN THE SUMMARY MATRIX

Potential Runways Threatened

	1	2	TOTAL
PROPOSED	9R - Turn R	10 - Turn L	
	27	32	59
Existing	9R - Turn L	8L - Turn R	
	10	23	33
Total	37	55	92

TABLE 3. DISTRIBUTION OF POTENTIAL AND VERIFIED PROBLEMS IN THE SUMMARY MATRIX (PERCENTAGES OF TOTAL IN PARENTHESES)

Potential Runways Threatened

Runway Configuration	1	2	Total
	9R - Turn R	10 - Turn L	
Modified	Total 27 Potential 2(0.76) Verified 1(.038)	Total 32 Potential 6(.188) Verified 3(.094)	Total 59 Potential 8(.135) Verified 4(.067)
	9R - Turn L	8L - Turn R	
Nominal	Total 10 Potential 0(.000) Verified 0(.000)	Total 23 Potential 2(.090) Verified 1(.045)	Total 33 Potential 2(.061) Verified 1(.030)
Total	Total 37 Potential 2(.054) Verified 1(.027)	Total 55 Potential 8(.145) Verified 4(.073)	Total 92 Potential 10(.109) Verified 5(.054)

There is an unusually high rate of verified problems (about 9 percent) for runway 10 turning left across traffic. This results both from the initial separation of 3000 feet between runway 10 and the adjacent runway 9R, and from the extremely sharp turns into the adjacent runway represented by the 30 degree blunders. Two of the three verified problems for runway 10 involved 30 degree excursions toward 9R, and two of the three involved simulated communication failures as well. This trend is seen across all the verified problem events. Four of five involve 30 degree turns (as do eight of the ten potential problems), and four of the five involve communication failures (as do seven of the ten potential problems). The significance of the communication failures is that the controller on the runway from which the excursions is made, who would ordinarily be the first to detect the problem and act, is unable to affect the outcome, and adjustments to the excursion must be handled solely by controllers on the threatened runways. The combination of 30 degree turns and failed communications is highly improbable, and the relatively high incidence of problems occurring under that condition should be viewed accordingly. It should also be noted that 95 percent of the blunders were managed by the controllers entirely without incident.

VERIFIED PROBLEMS. Time-track plots for the five verified problem events are given as figure 21. Table 4 shows horizontal and vertical separations at the point of closest proximity of the aircraft along with maximum API's associated with each conflict. The closest proximity of aircraft was about 1340 feet horizontal at approximately the same altitude. This occurred on two events. Note from the time track plots, however, that, in both cases, these closest points occurred after appropriate action had already been taken by the controllers, the situations had been brought "under control," and the aircraft had been established upon diverging flightpaths. In the first plot analyzed (run 28, plot P-4, figure 21 sheet 1), a Delta flight, DAL9982, blundered 30 degrees to the right of runway 9R threatening an Air South aircraft, ASE260, inbound to runway 10. ASE260 was turned to the right to resolve the conflict. At time hack "59," 590 seconds (or just under 10 minutes) after the run began, DAL9982 and ASE260 came within .22 nmi (1339.14 feet) of each other with 3 feet of altitude differential. Another Delta flight, DAL1906, approaching runway 8L was not threatened and was allowed to continue its approach. In the next conflict that was analyzed (run 27, plot P-15, figure 21 sheet 2), Air South Flight ASE211 blundered 30 degrees to the left which threatened the approaches to both 9R and 8L. American Airlines Flight AAL1015 was turned to the left to clear the blundering aircraft. Approximately 20 seconds later, Eastern Flight EAL265 was also turned out to the

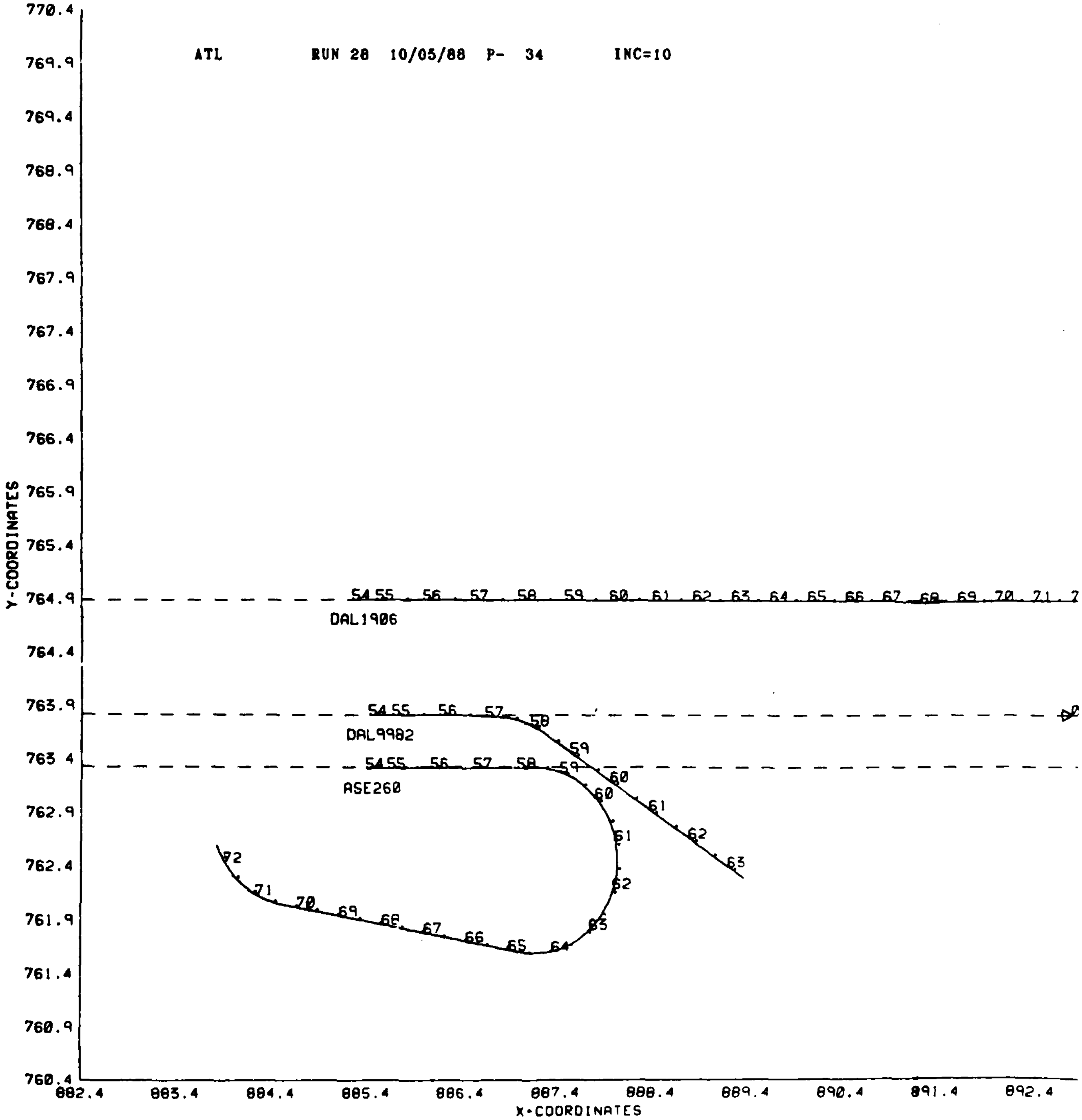

FIGURE 21. TIME-TRACK PLOT FOR VERIFIED PROBLEM EVENT (SHEET 1 OF 5)

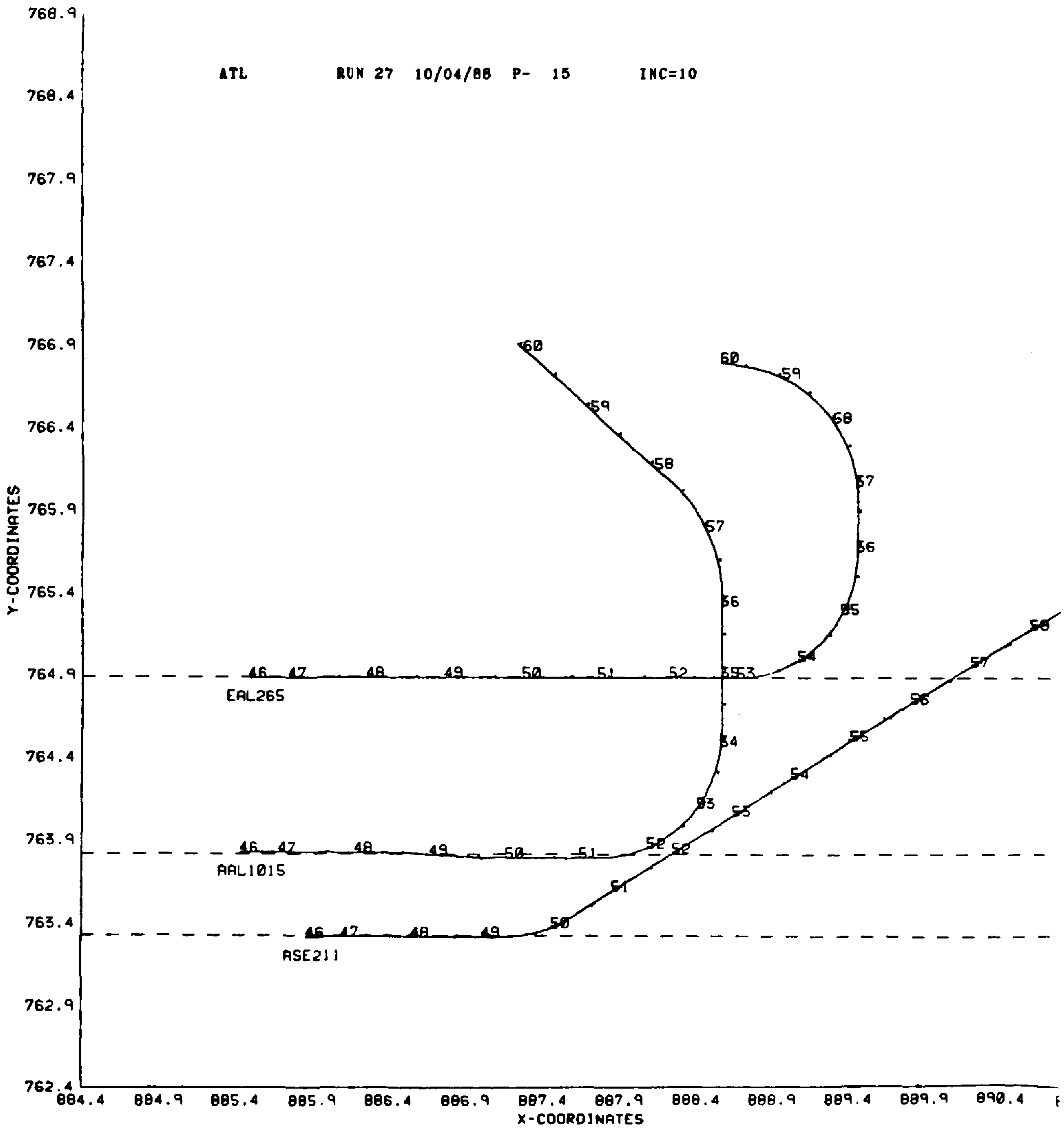

FIGURE 21. TIME-TRACKED PLOT FOR VERIFIED PROBLEM EVENT (SHEET 2 OF 5)

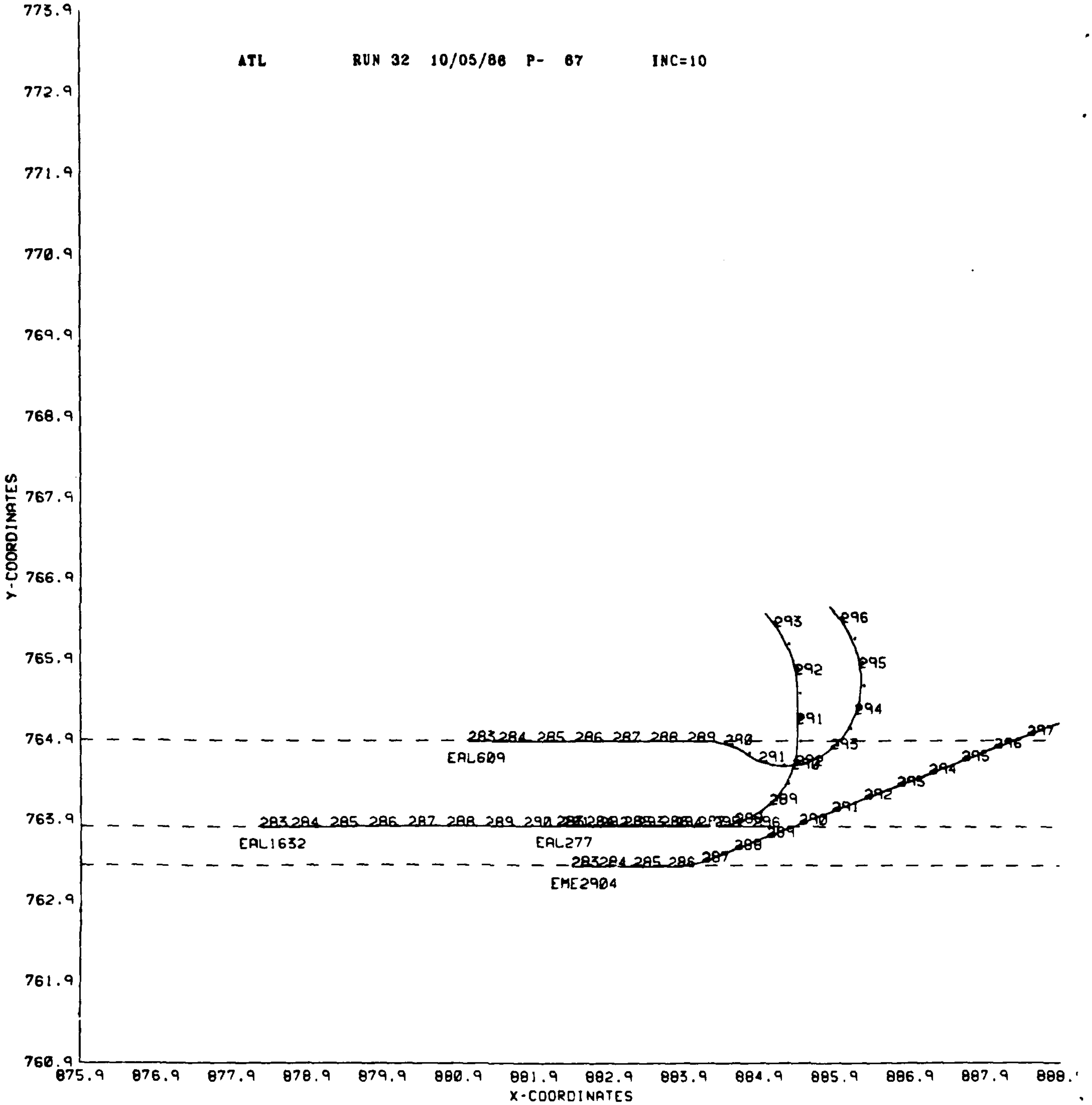

FIGURE 21. TIME-TRACKED PLOT OF VERIFIED PROBLEM EVENT (SHEET 3 OF 5)

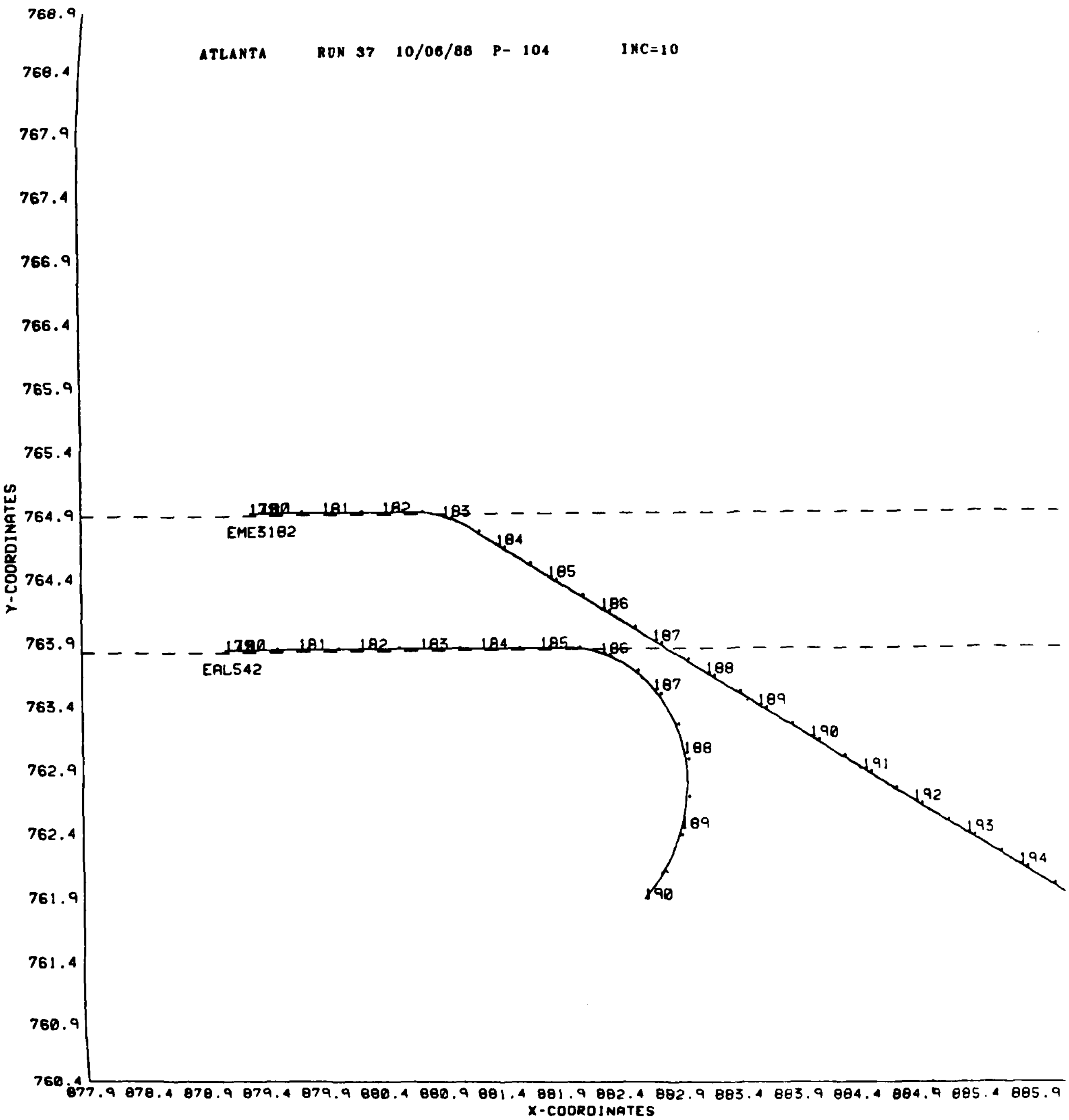

FIGURE 21. TIME-TRACK PLOT FOR VERIFIED PROBLEM EVENT (SHEET 4 OF 5)

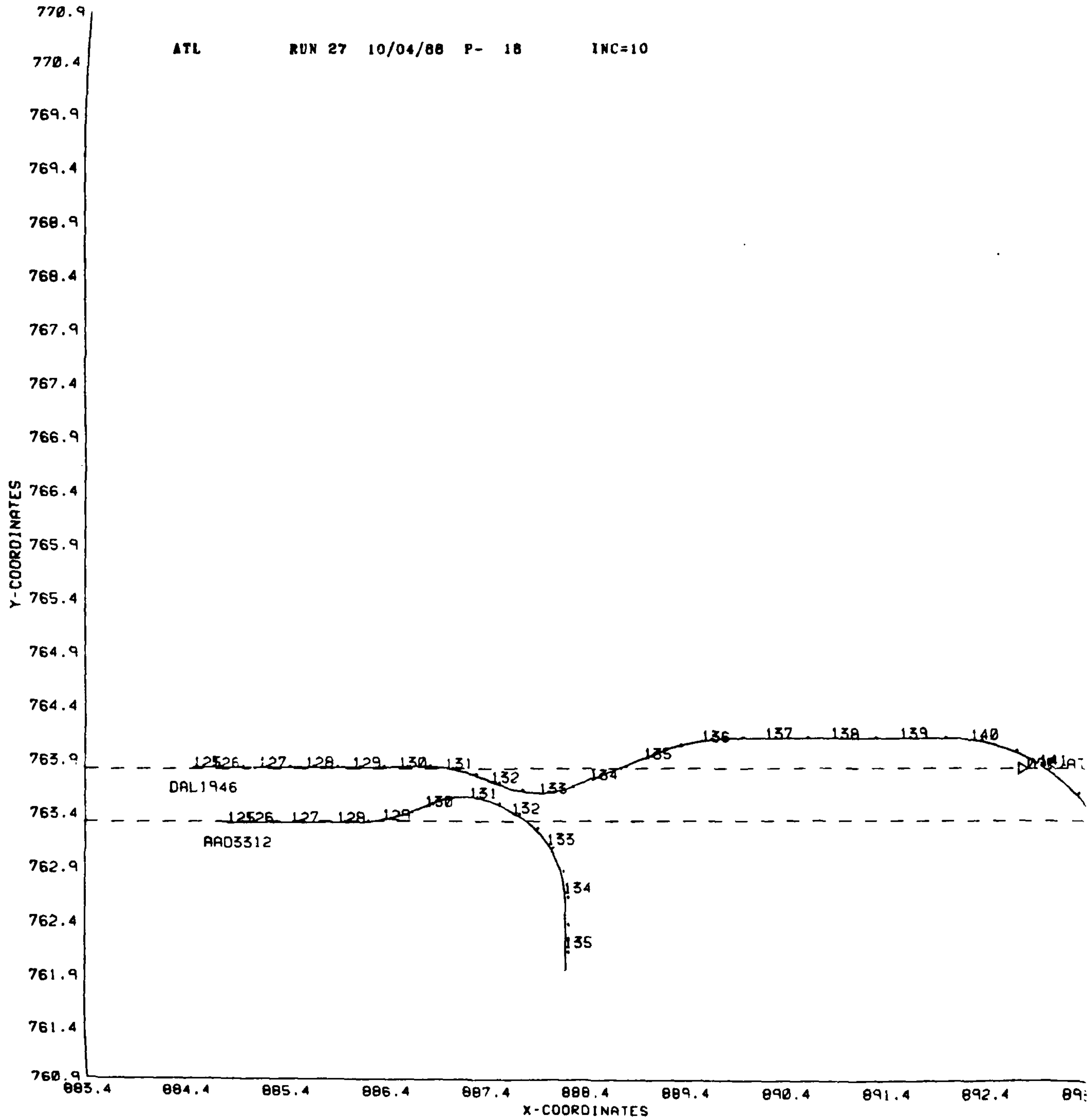

FIGURE 21. TIME-TRACK PLOT FOR VERIFIED PROBLEM EVENT (SHEET 5 OF 5)

TABLE 4. HORIZONTAL AND VERTICAL SEPARATION AND API AT CLOSEST PROXIMITY FOR VERIFIED PROBLEM EVENTS

Run No.	Plot No.	Blunder Degree	Comm Fail	Horiz Sep (nmi)	Vert Sep (ft)	Max API
28	34	30	Y	0.22	3	87
27	15	30	Y	0.23	3	85
32	67	30	Y	0.33	8	79
37	104	30	Y	0.35	9	78
27	18	20	N	0.36	4	79

left to insure separation. At time "52" (520 seconds after the simulation run began), the two aircraft (ASE211 and AAL1015) passed within 1400 feet of each other with 3 feet of vertical separation. In the next conflict (run 32, plot P-67, figure 21 sheet 3), Eastern etro Flight EME2904, approaching runway 10, blundered left toward runways 9R and 8L. Eastern Flight EAL277, inbound to runway 9R, was turned left to regain separation. Eastern Flight EAL 609, which was on the localizer for runway 8L, was also diverted to the left. At time hack 288 (2880 seconds, or approximately 48 minutes after the start of the run), EME2904 and EAL277 passed within 2000 feet of each other with 8 feet of vertical separation. In the fourth conflict (run 37, plot P-104, figure 21 sheet 4), at time 1825 (just over 30 minutes after the run began) Eastern Metro Flight EME3182 blundered 30 degrees to the right of the localizer for runway 8L and threatened Eastern Flight EAL542. Approximately 25 seconds later, EAL542 was turned to the right to resolve the conflict. At time 186, the two aircraft, EAL542 and EME 3182, passed within 0.33 nmi (or just over 2000 feet) of each other with 9 feet of vertical separation. It should be noted that in all four of these blunders, the blundering aircraft also simulated a complete loss of communications (NORDO).

Although each of these four problem events involves some element of separation that is below current standards, there does not appear to be undue hazard even in the worst case event due, in large part, to effective management of blunders by the controllers. In order to produce the worst case "hazards" observed in this simulation, it was necessary to have:

1. Two aircraft on adjacent runways 3000 feet apart,

2. The "blundering" aircraft leading the adjacent aircraft by about 0.5 nmi,

3. Both aircraft at, or near, the same altitude,

4. An immediate 30 degree turn into the adjacent runway, and

5. A simultaneous communications failure by the blundering aircraft.

Although this particular unique combination of circumstances is, at least theoretically, possible in actual operation, it would necessarily be considered extremely unlikely in a real world operational environment.

ANALYSIS OF VARIANCE. A general linear model Analysis of Variance (ANOVA) was conducted on the maximum API's associated with runway separation distance, the magnitude of the blunder (10, 20, or 30 degrees), and the number of runways threatened by the initial blunder. The findings were consistent with those of the graphic analyses. The extent of runway separation, the degree of blunder, and the number of runways threatened were all significant beyond the 0.025 level, with the strongest effect associated with the degree of blunder. The independent variables taken together accounted for approximately 45 percent of the variance of API, with the associated regression effects significant beyond the 0.001 level.

MULTIPLE BLUNDERS. In a fifth conflict identified as a "verified problem" (run 27, plot P-18, figure 21 sheet 5), Atlantis Flight AA03312 blundered 30 degrees left from the localizer for runway 10. Since AA03312 still had communications, it was turned out to the right to eliminate any threat to runway 9R. Approximately 30 seconds after the initiation of AA03312's blunder, Delta Flight DAL1946 began its own blunder to the right of the localizer for runway 9R. DAL1946, which also had communications, was routed back to the localizer. DAL1946 was ultimately turned out to reenter the approach pattern since it could not regain the localizer path in time for a safe completion of its landing. Since this conflict was the product of a simultaneous blunder, a rigorous application of the analysis rules would have excluded this simultaneous blunder conflict from further consideration. However, it was included to show that, even when faced with the most demanding challenge (converging simultaneous blunders across a 3000-foot runway separation), the monitors were able to resolve the conflict with a minimum lateral closure of 0.36 nmi (2191 feet). Data from an additional nine events in which multiple blunders occurred also yielded some findings of interest. First, none of these events produced any significant difficulties for the controller, and none produced either a potential or verified problem by the decision rules described above. Figures 22 and 23 are illustrations.

In figure 22, simultaneous blunders were initiated on runways 9R and 10 which caused the aircraft to turn toward each other across the 3000-foot separation between these two runways. This could be considered a worst case condition for this particular configuration. However, this potential hazardous convergence was resolved with 3500 feet lateral separation as the minimum closure distance. While not a true dual blunder, the event in figure 23 shows a blunder that affects two runways in opposite directions. The aircraft on 9R started a blunder to the left. The controller initiated a recovery turn toward the localizer. However, the aircraft overshot the approach path and started to close rapidly on runway 10. The runway 10 controller was able to divert his aircraft out to the right and maintain at least 1 mile of lateral separation.

The plots of all the blunders related approaches are contained in appendix C (volume II of this report). Appendix C-1 contains the plots of blunders which threatened one runway. The blunders which posed a threat to two runways are found in appendix C-2. The plots of blunders which resulted in "verified problems" are contained in appendix C-3.

CONTROLLER QUESTIONNAIRE RESPONSES. Controllers participating in the Atlanta simulations were afforded the opportunity to express their impressions in a questionnaire (shown in figure 19). Form questions covered the areas of:

Realism of the traffic (Realism).

How hard the controller had to work (Work Effort).

How well the controller felt he was able to control the traffic (Control).

How the controllers felt about the applicability of the simulated conditions to their facility (Acceptability).

Responses were compiled for each of the five configurations which were evaluated (see table 5). Table 6 quantifies the responses made to the five simulation configurations.

COMMENTS: The majority of the comments from the controllers related to improving the simulation, digital radar displays, and the ability to control traffic in these configurations. Seventeen comments were included in the 113 questionnaires.

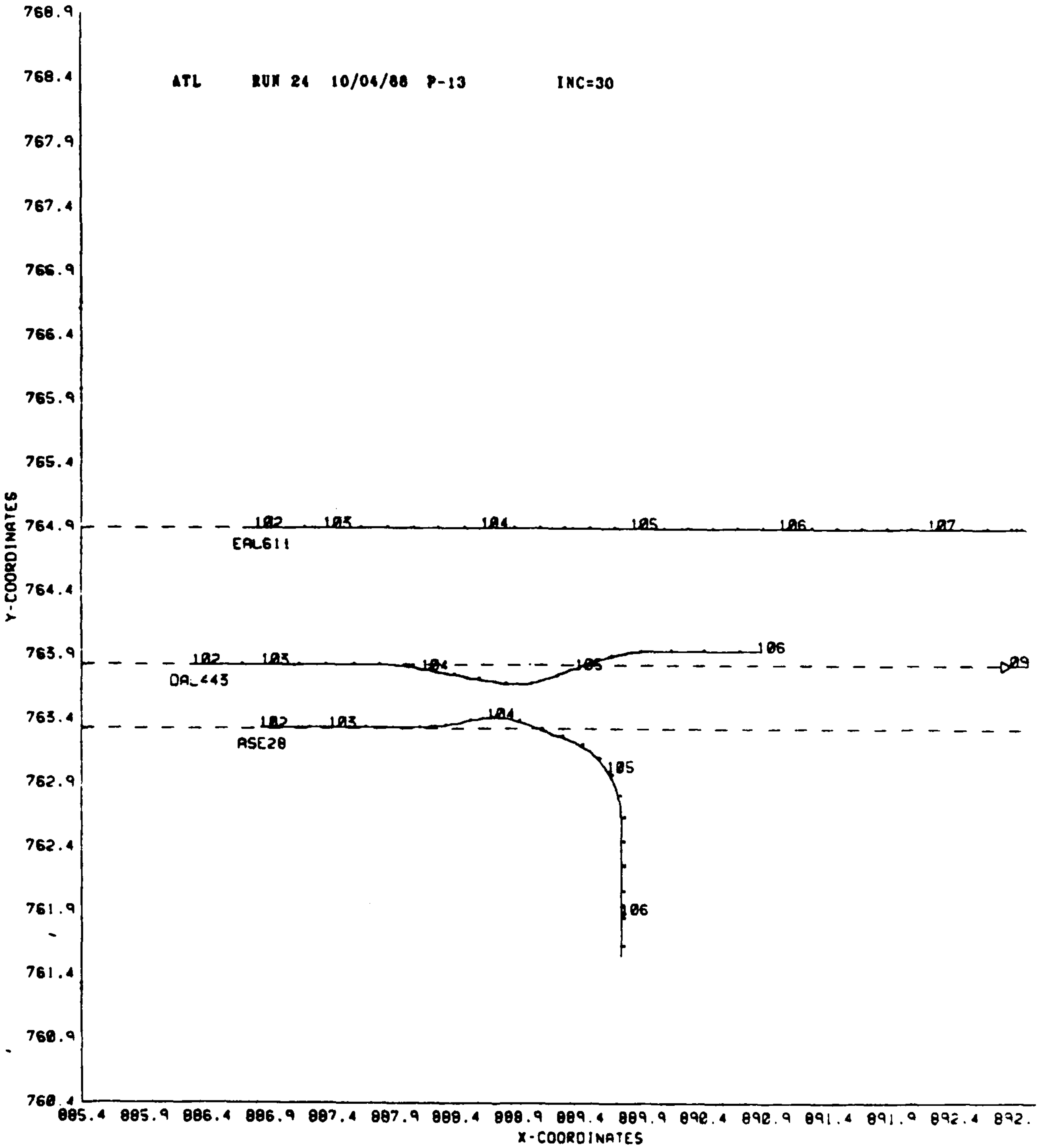

FIGURE 22. SIMULTANEOUS CONVERGING BLUNDERS ACROSS SHORT SEPARATION

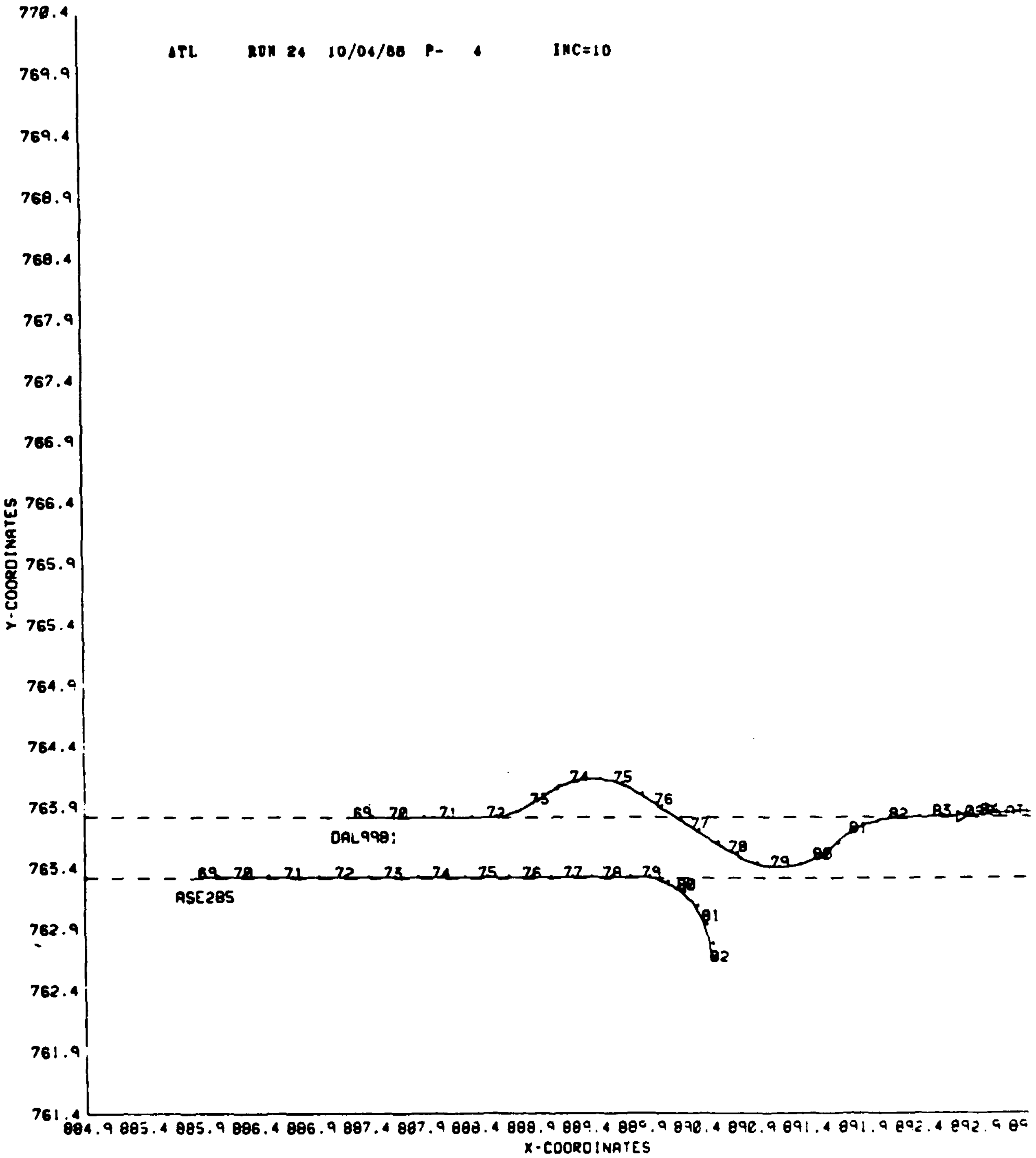

FIGURE 23. OVERSHOOT THREAT TO THE COMMUTER RUNWAY

TABLE 5. SIMULATION CONFIGURATIONS

(1) ATL 201	Approach Feeder Baseline; Current Runway Configuration
(2) ATL 202	Approach Feeder For Triple Parallel Runway Configuration
(3) ATL 203	Approach Feeder For Converging Runway Configuration
(4) ATL 204	Approach Monitoring For Triple Parallel Runways
(5) ATL 205	Approach Monitoring For Converging Runways

TABLE 6. SUMMARY OF CONTROLLER QUESTIONNAIRE RESPONSES

Conditions: ATL 201	Traffic Realism	Work Effort	Control	Acceptability of Conditions
Responses:	14			
Average:	3.21	1.93	4.14	4.07
Standard Deviation	0.67	0.96	0.91	0.80
Maxium Value	5	4	5	5
Minimum Value	2	0	2	3

Conditions: ATL 202	Traffic Realism	Work Effort	Control	Acceptability of Conditions
Responses:	30			
Average:	4.97	3.10	4.23	4.13
Standard Deviation:	4.60	1.04	0.92	0.81
Maximum Value:	5	5	5	5
Minimum Value:	3	0	2	3

Conditions: ATL 203	Traffic Realism	Work Effort	Control	Acceptability of Conditions
Responses:	29			
Average:	4.41	2.69	4.69	4.62
Standard Deviation:	0.77	1.46	0.53	0.61
Maximum Value:	5	5	5	5
Minimum Value:	2	0	3	3

Conditions: ATL 204	Traffic Realism	Work Effort	Control	Acceptability of Conditions
Responses:	19			
Average:	4.28	2.44	4.00	4.44
Standard Deviation:	0.99	1.01	1.00	0.68
Maximum Value:	5	5	5	5
Minimum Value:	1	0	1	3

Conditions: ATL 205	Traffic Realism	Work Effort	Control	Acceptability of Conditions
Responses:	22			
Average:	4.50	2.23	4.41	4.59
Standard Deviation:	0.72	0.85	0.72	0.58
Maximum Value:	5	4	5	5
Minimum Value:	2	0	3	3

Comments that appear to have system implications are listed below;

Comment:	Context:
Digital displays don't follow localizer very well. Planes on final are all over the place.	Controller: 812 Run #/Conditions: 5/202 Realism: 5 Work Effort: 4 Control: 2 Acceptability: 4
More airspace required out to 25 nmi for proper turn ons below traffic on final for 9R.	Controller: 850 Run #/Conditions: 6/202 Realism: 4 Work Effort: 2 Control: 4 Acceptability: 3
Normal Operating Zone (NOZ) too thin (500') on 9R/10.	Controller: 812 Run #/Conditions: 27/204 Realism: 1 Work Effort: 5 Control: 1 Acceptability: 3
Runway 6 Able to turn all missed approaches before he conflicted with 9R traffic.	Controller: 78 Run #/Conditions: 31/205 Realism: 5 Work Effort: 3 Control: 5 Acceptability: 5

CONVERGING OPERATIONS.

A series of simulation runs were also conducted in which standard approaches were made to runways 9R and 8L with additional approaches made to the converging runway, runway 6. A number of these runs involved blunders which could threaten one or more of the other runways. The plots of those blunders which involved runway 6 are contained in appendix C-4. All of these encounters were handled without incident. An example of a blunder from 9R toward runway 6 is shown in figure 24. In this case, the aircraft on flightpath to runway 6 was vectored to the south and cleared the approach area with more than minimal separation. In a more complex blunder induced situation (see figure 25) an aircraft bound for 8L blundered to the right. The controller

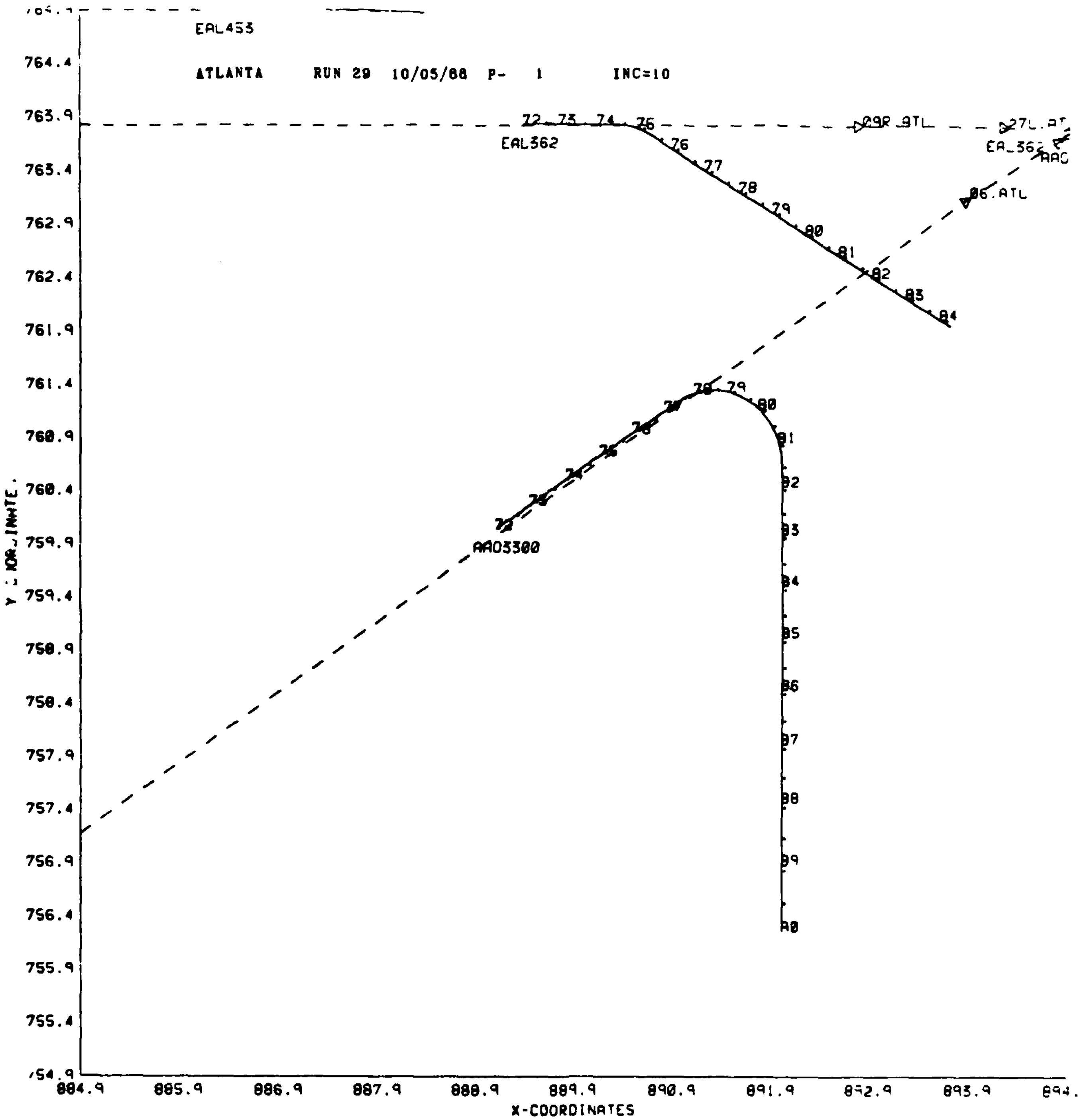

FIGURE 24. 30° BLUNDER TOWARD RUNWAY 6

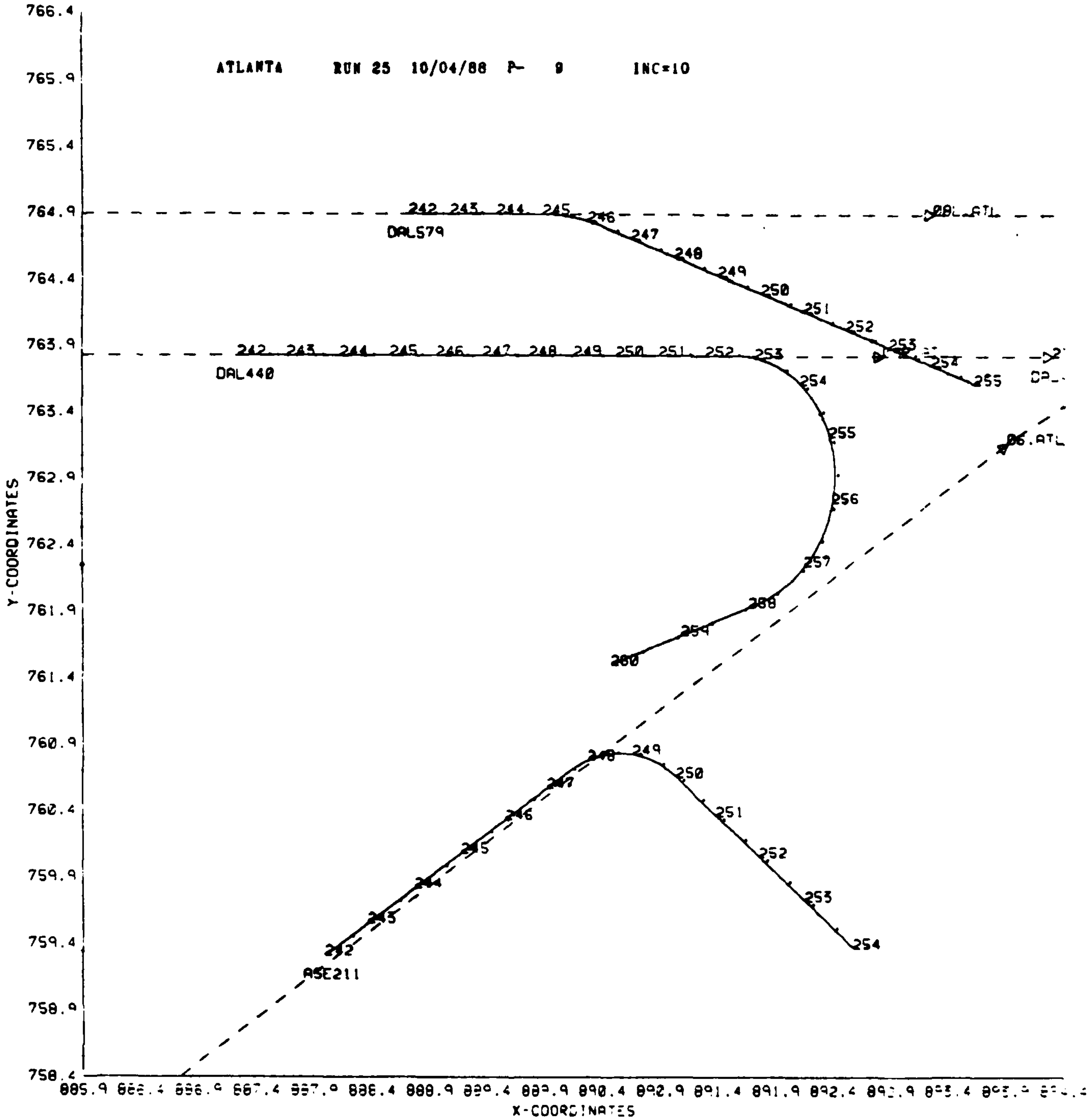

FIGURE 25. CASCADING BLUNDER TOWARD RUNWAY 6

monitoring runway 6 anticipated the potential for conflict between 8L and 9R and took his aircraft out and to the southeast, which allowed the aircraft on 9R sufficient room to divert and avoid the blundering aircraft. In two cases the aircraft on flightpath to runway 6 blundered toward the existing runways (see figures 26 and 27). In both cases, avoidance control was positive and effective.

In general, traffic to the converging runway configuration was handled smoothly and without significant incident, even in the presence of the extreme challenge of 30 degree NORDO blunders from runway 9R.

CAPACITY ENHANCEMENT.

There were no simulations conducted during this study in which operations were carried to touchdown on either of the proposed configurations which did not involve blunders. Therefore, it is not possible to make a direct assessment of the contribution of the addition of a third runway to operational capacity. However, there were periods of "normal" activity, which occurred between the introductions of blunders, in which aircraft proceeded routinely to touchdown. The interaircraft intervals were sampled for these periods for each runway. The statistical summary of these data for the third parallel configuration is shown in table 7. If the operational capacity is estimated using the mean values plus two standard deviations, a very conservative prediction, the adjusted simulation data would project an operational rate for this configuration of 92 operations per hour; an increase of 32 over the current level of 60/hour. The summary statistics for the converging runway data are contained in table 8. This analysis showed a slightly higher estimated capacity even though the estimated interaircraft interval for runway 6 was longer than that for runway 10. This might be attributable to the fact that use of the converging runway did not appear to disrupt the flow of traffic to the existing runways as much as did the operations to the third parallel.

CONCLUSIONS

The Technical Center conducted dynamic real-time simulations of selected aspects of the Atlanta Tower's Airport Enhancement Plan. Atlanta controllers, who served as subjects, evaluated traffic flow to a three-runway configuration with both a third parallel runway, 3000 feet south of the existing runway 9R and a 30 degree converging runway. The controllers comments indicated that the management of this traffic presented no significant problems to the third parallel or converging runway. Large numbers of blunders (deviations of inbound aircraft from their assigned localizer paths) were introduced to exercise the proposed system. In over 90 blunders during approaches to the third parallel runway, 5 resulted in closure distances between

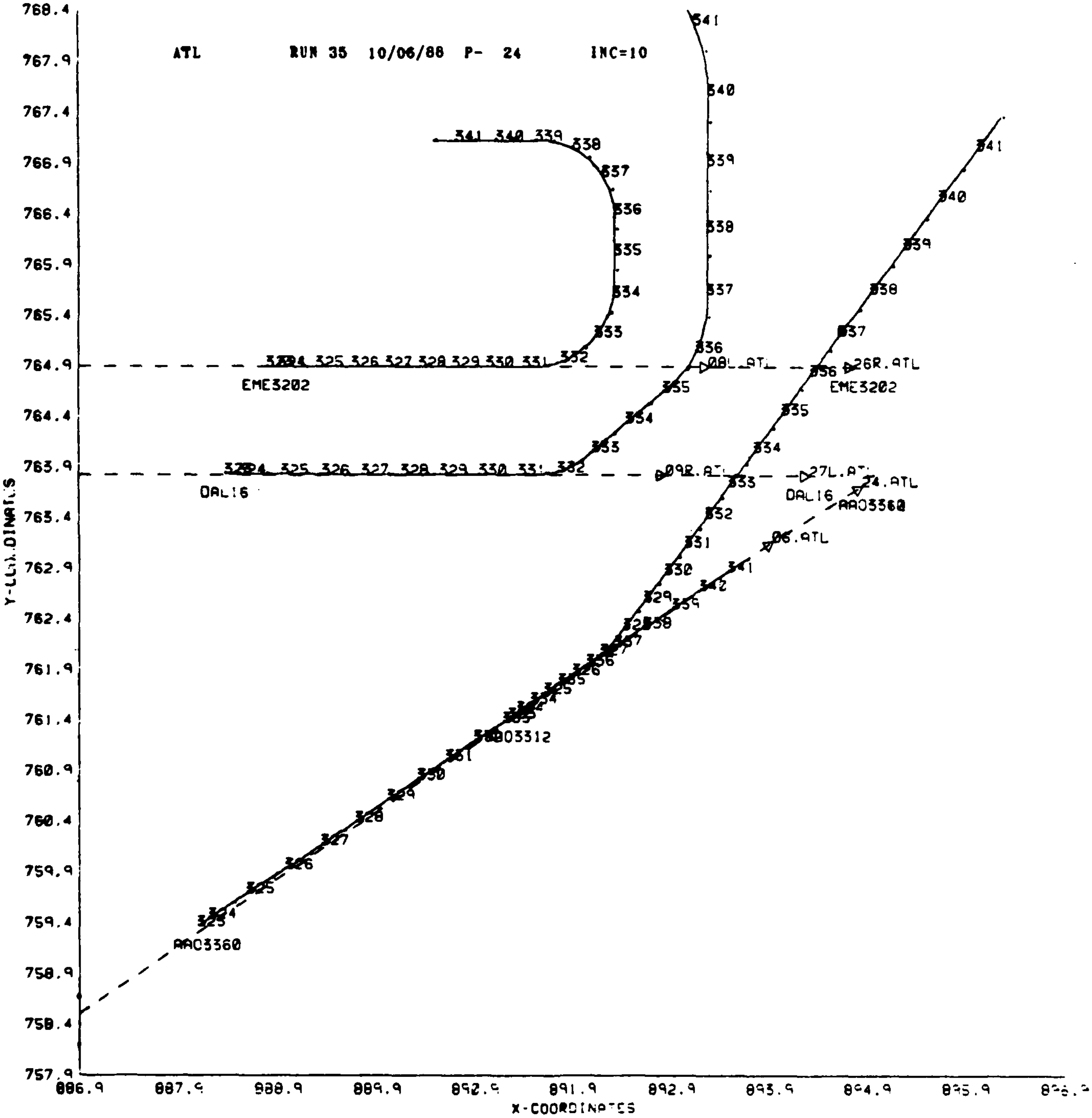

FIGURE 26. RUNWAY 6 BLUNDER: NORTH AVOIDANCE

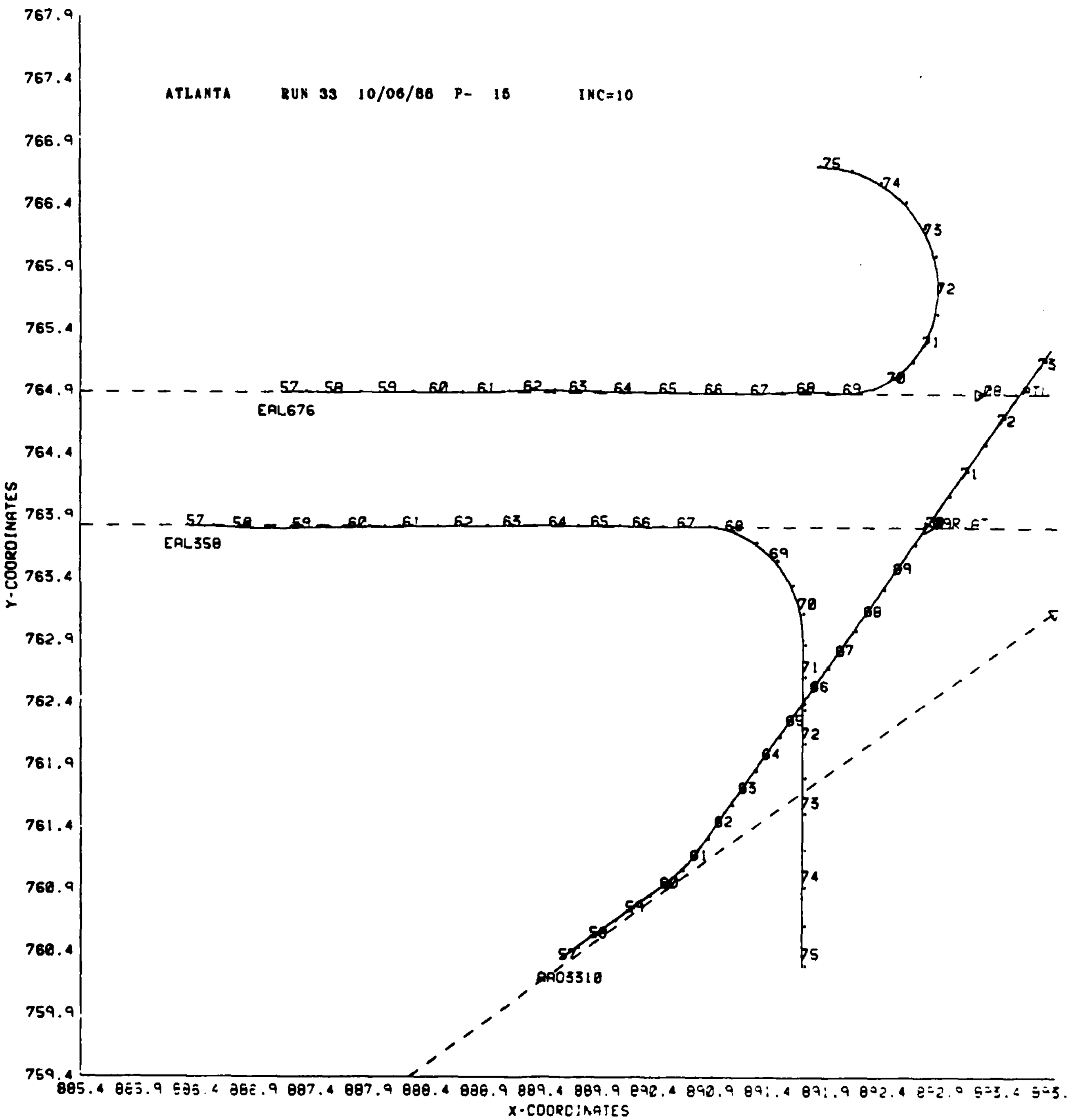

FIGURE 27. RUNWAY 6 BLUNDER: SPLIT AVOIDANCE

TABLE 7. TRAFFIC CAPACITY WITH A THIRD PARALLEL RUNWAY

Interaircraft Interval (sec)	8L	Runways 9R	10	Total
Average	79.63	86.00	95.08	
S.D.	16.32	14.79	13.56	
Max	124	119	132	
Min	49	67	79	
Average Ops/ Hour	45.21	41.86	37.86	124.93
*Adjusted Ops/Hour	32.07	31.15	29.46	92.68

*Average Inter-aircraft Interval (sec) minus two standard deviations converted to operations/hour.

TABLE 8. TRAFFIC CAPACITY WITH A CONVERGING THIRD RUNWAY

Interaircraft Interval (Sec)	8L	Runways 9R	6	Total
Average	86.71	81.2	112.5	
S.D.	3.84	6.31	27.72	
Max	95	92	158	
Min	82	74	80	
Average Ops/ Hour	41.52	44.33	32.00	117.85
*Adjusted Ops/Hour	38.12	38.37	21.44	97.93

*Average Inter-aircraft Interval (sec) minus two standard deviations converted to operations/hour.

aircraft small enough to merit detailed analysis. The smallest horizontal distance involved 30 degree blunders across the 3000-foot separation with four of these also simulating a complete loss of communications. The overall simulation results denomstrated the controllers' ability to maintain an orderly flow of traffic to both the triple parallel and converging runway configurations. When repeatedly challanged by the unlikely combination of 30 degree NORDO blunders, 94 percent of the blunders were managed without incident. It must be kept in mind that the capacity increases for the converging runway configuration would not be attainable during instrument (IFR) weather conditions or in conjunction with runway 9L departures.

Since the simulations used a 1-second update rate, high resolution radar system, any extrapolation of these findings to the Atlanta complex must be predicated upon the installation of a comparable system at the Atlanta Facility.

The decision on runway separation distances for new construction of runways in Atlanta should not be based solely on the results of this simulation. Additional relevant data are now available which could affect the results, including navigation data from Chicago O'Hare, and automation and radar data being collected at Memphis and Raleigh-Durham.

Potential capacity restraints are possible based on a combination of flight technical error (FTE) around the localizer and a normal operating zone (NOZ) reduced to 500 feet. There are a number of technological innovations ongoing to be considered that are being tested by the high update sensors at Raleigh-Durham and Memphis and the associated automation features.

APPENDIX A

AIRCRAFT PROXIMITY INDEX
DESCRIPTION

BACKGROUND

Air Traffic Control (ATC) simulation is an essential research tool for the improvement of the National Airspace System (NAS). Simulation can never offer all of the complexity and subtlety of the real world, with live radar, actual aircraft, full communications systems, and the rest of the ATC environment, but it can provide an intensive exercise of key portions of the system -- with controllers in the loop.

Proper use of simulation starts with carefully defining the questions to be answered and then developing a simulation environment which includes the features that could influence the process under study. The selection of a simulation environment, the development of scenarios, the choice of data to be recorded, and the method of analysis are part science, part art.

An important benefit of simulation is that it permits the exploration of systems, equipment failures, and human errors that would be too dangerous to study with aircraft, or that occur so rarely in the system that they cannot be fully understood and evaluated. A current example of this use has to do with the introduction of blunders in parallel runway instrument approaches. (A blunder is defined as an unexpected turn towards an adjacent approach by an aircraft already established on the instrument landing system (ILS)).

The introduction of large numbers of system errors is a useful way to study safety, but the analysis of the outcomes of these incidents is not always simple or clear cut.

SAFETY EVALUATION

CONFLICTS.

The occurrence of a conflict in normal ATC operations is considered prima facie evidence of a human or system error. Identifying (and counting) conflicts under a variety of normal conditions is one way to expose a system problem.

A conflict is defined as the absence of safe separation between two aircraft flying instrument flight rules (IFR). At its simplest, safe separation requires: (a) the aircraft must be laterally separated by 3 or 5 nautical miles (nmi), depending on distance from the radar, (b) vertical separation by 1,000 or 2,000 feet, depending on altitude or flight level, or (c) that both aircraft are established on ILS localizers.

There are refinements of the above rules that take into consideration the fact that one aircraft may be crossing behind another, or that an aircraft has begun to climb or descend from a previous altitude clearance. There are special "wakes and vortices" restrictions for aircraft in trail behind heavy aircraft.

Since actual conflicts are rare, every event leading up to them and all the information available on the onset and resolution is carefully analyzed. The emphasis is on the intensive investigation of the particular event.

In scientific investigation, the intensive study of a single individual or a particular event is called the "idiographic" approach. This is often contrasted with the "nomothetic" approach: the study of a phenomenon or class of events by looking at large numbers of examples and attempting to draw general conclusions through the application of statistics.

The idiographic approach is mandatory for accident or incident investigation where the goal is to get as much information as possible about a unique event in order to prevent future occurrences.

In a simulation experiment, where the goal is to make a comparison between two or more systems (two vs three or four runways, 4300- vs 3000-foot runway spacing, etc.) and to generalize beyond the simulation environment, the nomothetic approach is most appropriate. This means generating a large number of events and statistically analyzing the outcomes with respect to the system differences.

There is much to be gained by studying the individual conflicts in a simulation as an aid to understanding the kinds of problems that occur and to generate hypotheses about how a system might be improved for subsequent testing. But the evaluation of the systems under test requires the use of all of the valid data, analyzed in as objective a manner as possible. Valid data in this context means that it was collected under the plan and rules of the simulation and was not an artifact, such as a malfunction of the simulation computer or distraction by visitors.

SLANT RANGE.

If it is important to go beyond the counting of conflicts - measurement of the distance between the conflicting aircraft pair is required. The most obvious measure is slant range separation: the length of an imaginary line stretched between the centers of each aircraft. Over the course of the incident that distance will vary, but the shortest distance observed is one indication of the seriousness or danger of the conflict.

The problem with slant range is that it ignores the basic definition of a conflict and is insensitive to the different standards that are set for horizontal and vertical separation. A slant range distance of 1,100 feet might refer to 1,000 feet of vertical separation, which is normally perfectly safe, to less than 0.2 nmi of horizontal miss distance, which would be considered by most people to be a very serious conflict.

Slant range, per se, is too ambiguous a metric to have any real analytical value.

AIRCRAFT PROXIMITY INDEX (API).

The need exists for a single value that reflects the relative seriousness or danger. The emphasis here is on "relative," since with the nomothetic or statistical approach, an absolute judgment of dangerous or safe is useful, but not sensitive enough. The requirement is to look at the patterns of the data for the different experimental conditions and determine whether one pattern indicates more, less, or the same degree of safety as another.

Such an index should have to have certain properties.

1. It should consider horizontal and vertical distances separately, since the ATC system gives 18 times the importance to vertical separation (1,000 ft vs 3 nmi).

2. It should increase in value as danger increases, and go to zero when there is no risk, since the danger in the safe system is essentially indeterminate.

3. It should have a maximum value for the worst case (collision), so that users of the index can grasp its significance without tables or additional calculations.

4. It should make the horizontal and vertical risk or danger independent factors, so that if either is zero, i.e., safe, their product will be zero.

5. It should be a nonlinear function, giving additional weight to serious violations, since they are of more concern than a number of minor infractions.

The API is designed to meet these criteria. It assigns a weight or value to each conflict, depending on vertical and lateral separation. API facilitates the identification of the more serious (potentially dangerous) conflictions in a data base where many conflictions are present. One hundred has been chosen, somewhat arbitrarily, for the maximum value of the API.

APPROACH.

During a simulation API can be computed whenever a conflict exists. For convenience, this is taken to be when two aircraft have less than 1,000 feet of vertical separation and less than 3.0 miles of lateral separation. It is computed once per second during the conflict. The API of the conflict is the largest value obtained.

API considers vertical and horizontal distances separately, then combines the two in a manner than gives them equal weight; equal in the sense that a loss of half the required 3.0 nmi horizontal separation has the same effect as the loss of half the required 1000 feet of vertical separation.

COMPUTATION.

The API ranges from 100 for a midair collision to 0 for the virtual absence of a technical confliction. A linear decrease in distance between the aircraft, either vertically or laterally, increases the API by the power of 2.

Computation is as follows:

D_V = vertical distance between aircraft (a/c) (in feet)
D_H = horizontal distance (nmi (6,076'))
API = $(1{,}000-D_V)^2 * (3-D_H)^2/(90{,}000)$

To simplify its use, API is rounded off to the nearest integer, i.e.,

API = $\mathrm{INT}((1{,}000-D_V)^2 * (3-D_H)^2/(90{,}000)+.5)$

The rounding process zeros API's less than 0.5. This includes distances closer than 2 nmi and 800 feet. The contour plot in figure A-1 demonstrates the cutoff for API = 1.

See tables A-1 and A-2 for typical values of API at a variety of distances.

Figure A-2 is a three-dimensional plot showing the relationship between API and vertical and horizontal separation graphically. Figure A-3 shows the same information in a slightly different way. Anything outside the contour at the base is "0." In figure A-4 a contour plot of API for horizontal and vertical distances from 0 to 500 feet is shown, with 300-foot and 500-foot slant range distances superimposed.

DISCUSSION

The index is not intended as a measure of acceptable risk, but it meets the need to look at aircraft safety in a more comprehensive way than simply counting conflictions or counting the number of aircraft that came closer than 200 feet, or some other arbitrary value.

It should be used to compare conflicts in similar environments i.e., an API of 70 in en route airspace with speeds of 600 knots is not necessarily the same concern as a 70 in highly structured terminal airspace with speeds under 250 knots.

Since the API is computed every second, it may be useful to examine its dynamics over time as a means of understanding the control process.

TABLE A-1. TYPICAL VALUES

Vertical Distance (D_V)	Horizontal Distance in Nautical Miles (1 nmi = 6076') (D_H) in Feet																
	3	2.5	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05	0.01	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
800	0	0	0	1	2	2	2	2	3	3	3	3	3	4	4	4	4
700	0	0	1	2	4	4	5	5	6	6	7	7	8	8	9	9	9
600	0	0	2	4	7	8	9	9	10	11	12	13	14	15	15	16	16
500	0	1	3	6	11	12	13	15	16	17	19	20	22	23	24	25	25
400	0	1	4	9	16	18	19	21	23	25	27	29	31	34	35	36	36
300	0	1	5	12	22	24	26	29	31	34	37	40	43	46	47	49	49
200	0	2	7	16	28	31	34	38	41	44	48	52	56	60	62	64	64
100	0	2	9	20	36	40	44	48	52	56	61	66	71	76	78	80	81
-0-	0	3	11	25	44	49	54	59	64	69	75	81	87	93	97	99	100

TABLE A-2. ADDITIONAL VALUES

D_H	D_V	API	D_H	D_V	API	D_H	D_V	API
3.0	1000	0	1.0	667	5	0.05	667	11
3.0	0	0	1.0	500	11	0.05	500	24
0	1000	0	1.0	333	20	0.05	333	43
2.0	667	1	1.0	250	25	0.05	250	54
2.0	500	3	1.0	100	36	0.05	100	78
2.0	333	5	1.0	0	44	0.05	0	97
2.0	250	6	0.5	667	8	0.01	667	11
2.0	100	9	0.5	500	17	0.01	500	25
2.0	0	11	0.5	250	39	0.01	333	44
1.5	667	3	0.5	100	56	0.01	250	56
1.5	500	6	0.5	0	69	0.01	100	80
1.5	333	11	0.1	667	10	0.01	0	99
1.5	250	14	0.1	500	23	0	667	11
1.5	100	20	0.1	250	53	0	500	25
1.5	0	25	0.1	100	76	0	333	44
			0.1	0	93	0	250	56
						0	100	81

A/C PROXIMITY INDEX (API)

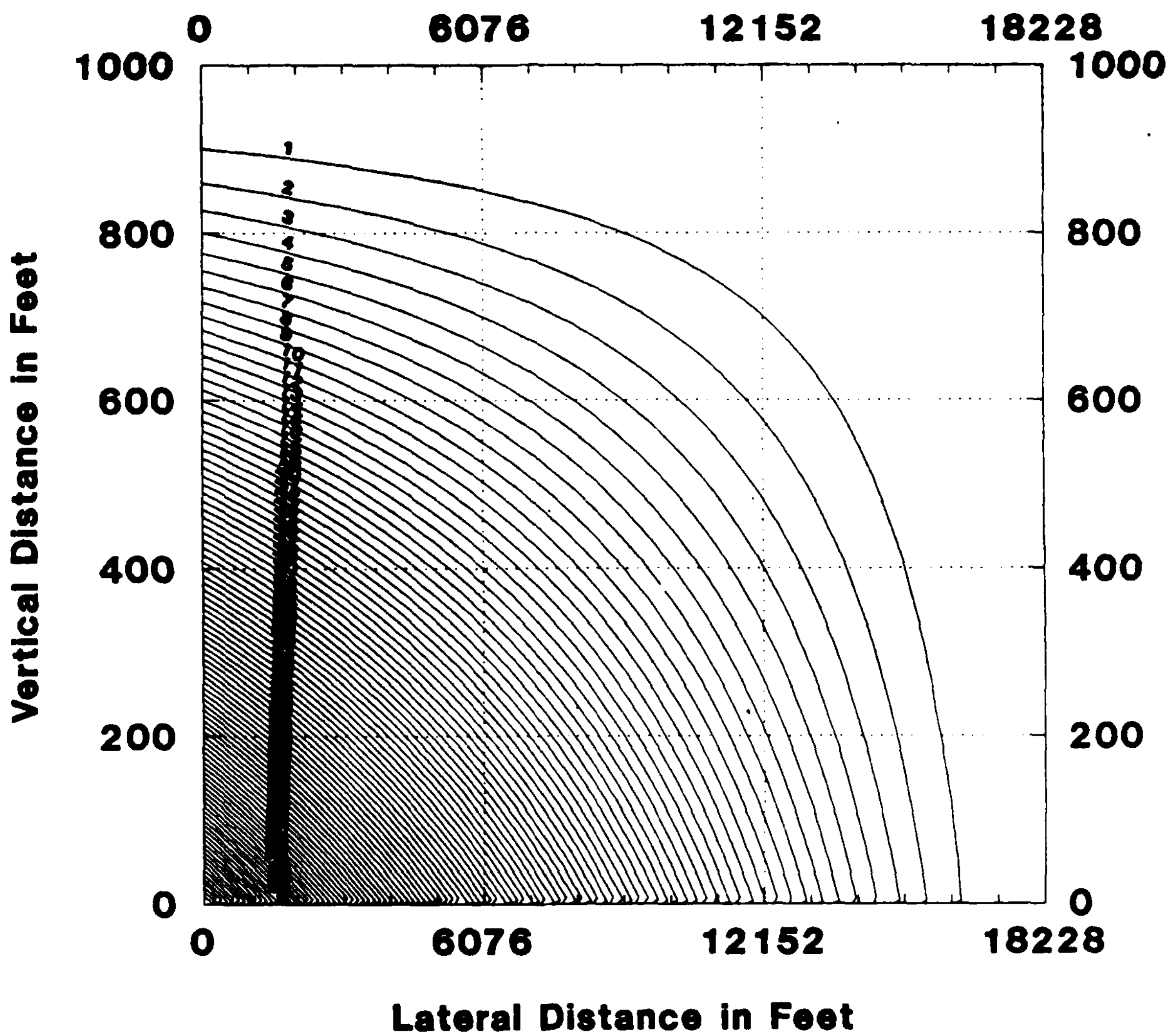

FIGURE A-1. CONTOUR PLOT

This is a contour plot of API showing the values of API for the horizontal separations of 0 to 3 nmi, and vertical separation of 0 to 1,000 feet. Values less than API = 0.5 round to zero. This includes a/c separated by as little 1.6 nm horizontally and 850 feet vertically.

AIRCRAFT PROXIMITY INDEX (API)

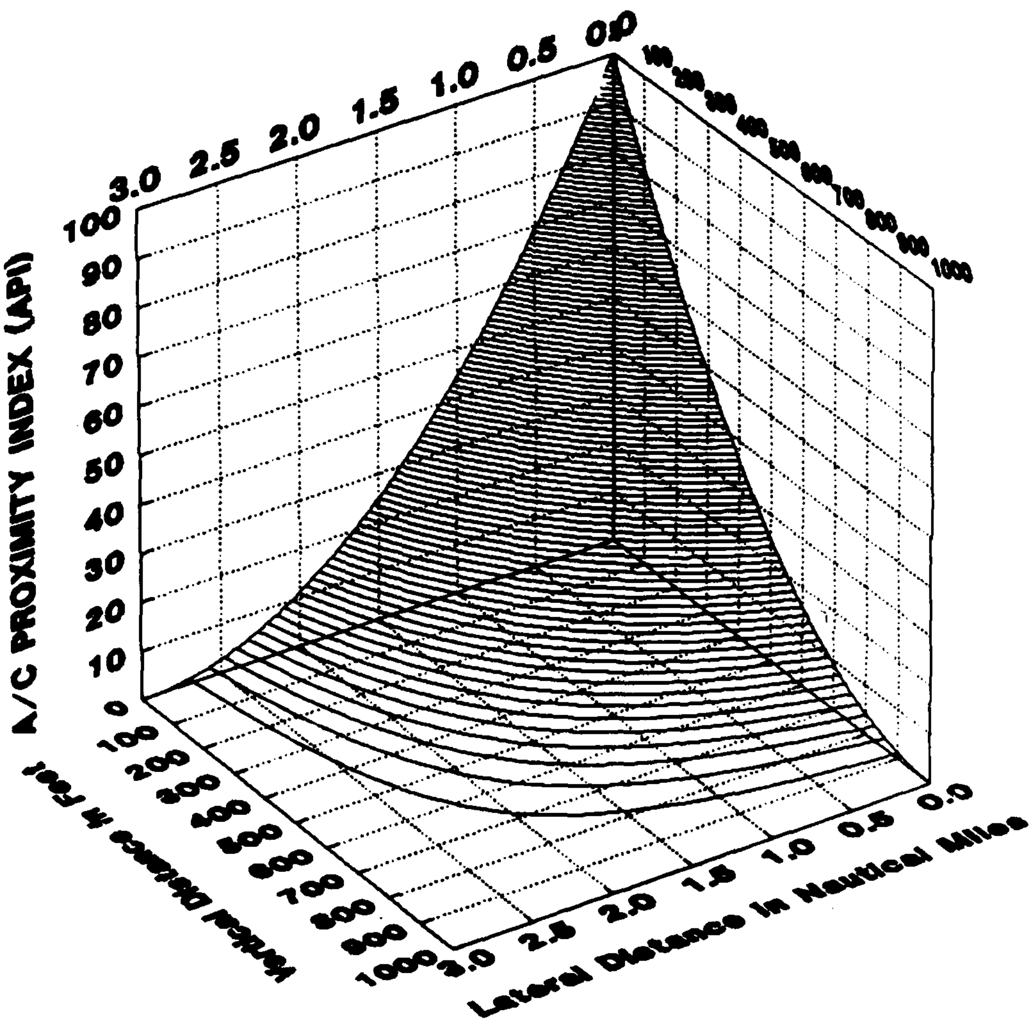

FIGURE A-2. THREE-DIMENSIONAL CONTOUR PLOT

Three-dimensional contour plot of API, for horizontal separations of 0 to 3 nmi, and vertical separations of 0 to 1,000 feet.

AIRCRAFT PROXIMITY INDEX (API)

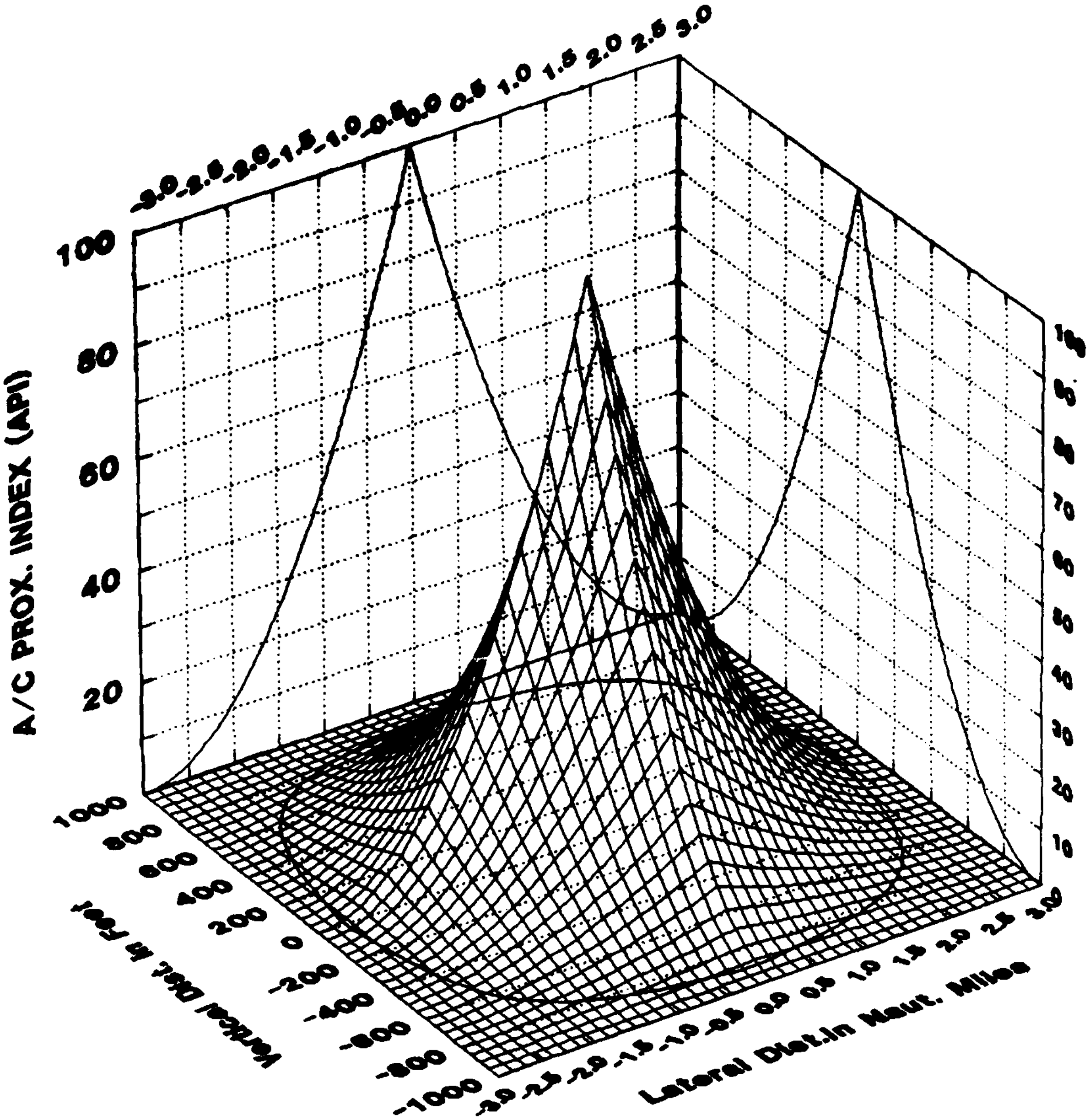

FIGURE A-3. THREE-DIMENSIONAL CONTOUR PLOT

Left vertical plane shows API vs horizontal distance with vertical distance = 0. Right vertical plane shows API vs vertical separation with horizontal distance = 0. Right vertical plan shows API vs vertical separation with horizontal distance = 0.

Plot may be interpreted by considering one a/c at the center of the base plane, while the height of the figure shows the API for another a/c anywhere else on the base plane.

The contour on the base plane shows the boundary between API = 0 and API = 1.

A/C PROXIMITY INDEX (API)

API VALUES FOR SLANT RANGES OF 300 AND 500 FEET

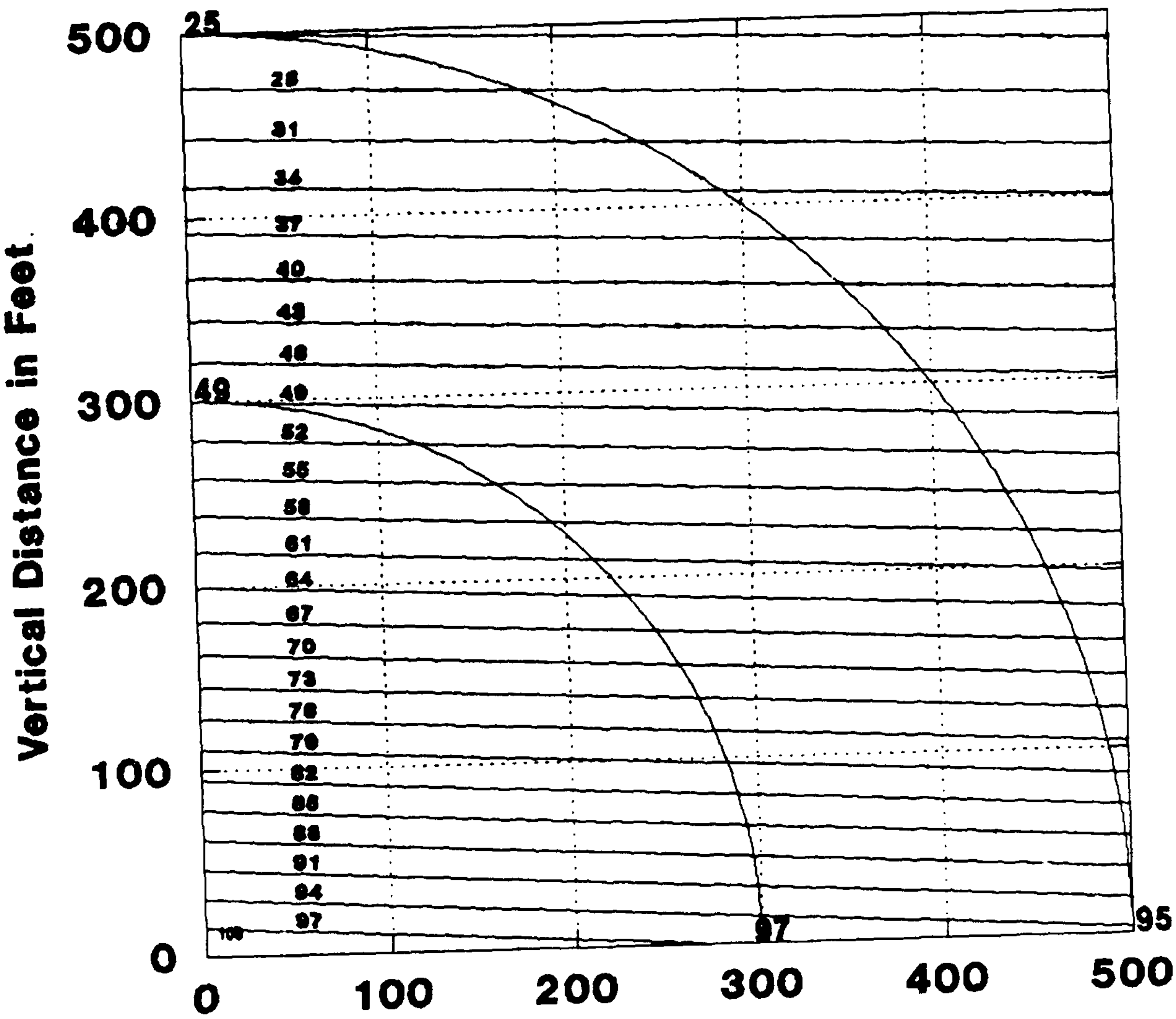

FIGURE A-4. CONTOUR PLOT OF API FOR HORIZONTAL AND VERTICAL DISTANCES OF 0 TO 500 FEET, SHOWING SLANT RANGE CONTOURS OF 300 AND 500 FEET

This plot shows the API values (the small numbers, inside the square running from 25 at the top to 100 at the bottom) for equal API contours (the slightly sloping horizontal lines) for horizontal and vertical distances of 0 to 500 feet. API values range from 25 (500 feet vertical, 0 horizontal separation) to 100 (0/0).

The 500-foot slant range contour has API values ranging from 25 to 95, depending on amount of vertical component. The 300-foot slant range contour runs from API = 49 to 97. Using API as a criterion, 500-foot slant range can be more dangerous than 300-foot.

APPENDIX B

PROJECTED CLOSET POINT OF APPROACH
(PCPA) COMPUTATIONS

CALCULATION OF PCPA AND TIME-TO-PCPA

Consider two aircraft (A and B) having X, Y, and Z spatial positions (coordinates) at Time i; that is:

Position of A/C_A at $Time_i$ = $X_{A_i}, Y_{A_i}, Z_{A_i}$, and (1.1)

Position of A/C_B at $Time_i$ = $X_{B_i}, Y_{B_i}, Z_{B_i}$, and (1.2)

The same A/C also have X, Y, and Z locations at Time i + 1:

Position of $A/C_A = X_{A_{i+1}}, Y_{A_{i+1}}, Z_{A_{i+1}}$ at Time = i +1. (2.1)

Position of $A/C_B = X_{B_{i+1}}, Y_{B_{i+1}}, Z_{B_{i+1}}$ at Time = i +1. (2.2)

The change in locations of the two aircraft between $Time_i$ and i +1 will be (subtracting eqs. 1.1 from 2.1 and 1.2 from 2.2):

$$\Delta X_A = X_{A_{i+1}} - X_{A_i};\ \Delta Y_A = Y_{A_{i+1}} - Y_{A_i};\ \Delta Z_A = Z_{A_{i+1}} - Z_{A_i} \quad (3.1)$$

$$\Delta X_B = X_{B_{i+1}} - X_{B_i};\ \Delta Y_B = Y_{B_{i+1}} - Y_{B_i};\ \Delta Z_B = Z_{B_{i+1}} - Z_{B_i} \quad (3.2)$$

The slant range (SR) between A/C_A and A/C_B at $Time_i$ =

$$SR_{AB_i} = \left[\left(X_{A_i} - X_{B_i}\right)^2 + \left(Y_{A_i} - Y_{B_i}\right)^2 + \left(Z_{A_i} - Z_{B_i}\right)^2 \right]^{.5} \quad (4.0)$$

Assuming that both A/C continue along the vectors defined by their locations at $Time_i$ and $Time_{i+1}$, then SR at Time "s" later will be found by

$$SR_{AB_{i+s}} = \Big[\left(\left(X_{A_i} + s \cdot \Delta X_A\right) - \left(X_{B_i} + s \cdot \Delta X_B\right)\right)^2$$
$$+ \left(\left(Y_{A_i} + s \cdot \Delta Y_A\right) - \left(Y_{B_i} + s \cdot \Delta_{B_i}\right)\right)^2 \quad (5.0)$$
$$+ \left(\left(Z_{A_i} + s \cdot \Delta Z_A\right) - \left(Z_{B_i} + s \cdot \Delta Z_B\right)\right)^2 \Big]^{.5}$$

$$= \Big[\left(\left(X_{A_i} - X_{B_i} \right) + s \left(\Delta X_A - \Delta X_B \right) \right)^2$$

$$+ \left(\left(Y_{A_i} - Y_{B_i} \right) + s \left(\Delta Y_A - \Delta Y_B \right) \right)^2 \qquad (5.1)$$

$$+ \left(\left(Z_{A_i} - Z_{B_i} \right) + s \left(\Delta Z_A - \Delta Z_B \right) \right)^2 \Big]^{.5}$$

$$= \Big[\left(X_{A_i} - X_{B_i} \right)^2 + s^2 \left(\Delta X_A - \Delta X_B \right)^2 + 2s \left(X_{A_i} - X_{B_i} \right) \left(\Delta X_A - \Delta X_B \right)$$

$$+ \left(Y_{A_i} - Y_{B_i} \right)^2 + s^2 \left(\Delta Y_A - \Delta Y_B \right)^2 + 2s \left(Y_{A_i} - Y_{B_i} \right) \left(\Delta Y_A - \Delta Y_B \right)$$

$$+ \left(Z_{A_i} - Z_{B_i} \right)^2 + s^2 \left(\Delta Z_A - \Delta Z_B \right)^2 + 2s \left(Z_{A_i} - Z_{B_i} \right) \left(\Delta Z_A - \Delta Z_B \right) \Big]^{.5}$$

$$= \Big[SR_{AB_i}{}^2 + s^2 \left(\left(\Delta X_A - \Delta X_B \right)^2 + \left(\Delta Y_A - \Delta Y_B \right)^2 + \left(\Delta Z_A - \Delta Z_B \right)^2 \right)$$

$$+ 2s \left(\left(X_{A_i} - X_{B_i} \right) \left(\Delta X_A - \Delta X_B \right) + \left(Y_{A_i} - Y_{B_i} \right) \left(\Delta Y_A - \Delta Y_B \right) \right.$$

$$\left. + \left(Z_{A_i} - Z_{B_i} \right) \left(\Delta Z_A - \Delta Z_B \right) \right) \Big]^{.5}$$

Since the X, Y, Z and Δ_X, Δ_Y, Δ_Z values are known for each aircraft, we can let:

$$C_1 = \left[\left(\Delta X_A - \Delta X_B \right)^2 + \left(\Delta Y_A - \Delta Y_B \right)^2 + \left(\Delta Z_A - \Delta Z_B \right)^2 \right] \qquad (6.1)$$

and

$$C_2 = \left[\left(X_{A_i} - X_{B_i} \right) \left(\Delta X_A - \Delta X_B \right) + \left(Y_{A_i} - Y_{B_i} \right) \left(\Delta Y_A - \Delta Y_B \right) + \left(Z_{A_i} - Z_{B_i} \right) \left(\Delta Z_A - \Delta Z_A \right) \right] \qquad (6.2)$$

Substituting these values into the previous equation

$$SR^2{}_{AB_{i+s}} = SR^2{}_{AB_i} + s^2C_1 + 2s\,C_2 \tag{7.0}$$

Differentiating $SR_{AB_{i+s}}$ with respect to s, we obtain

$$\frac{SR^2{}_{AB_{i+s}}}{d_s} = 2C_1\,s + 2C_2 \tag{7.1}$$

To find the minima, we set the left side of Eq. (7.1) to zero and solve for "s".

$$o = 2C_1 s + 2C_2$$

$$s = \frac{-C_2}{C_1} \tag{8.0}$$

Solving for "s", we can now solve for $SR^2{}_{AB_{i+s}}$ using Eq. (7.0) and, taking the square root we obtain the projected slant range at $Time_{i+s} = (SR^2{}_{AB_{i+s}})$.

Thus, for any two consecutive (and simultaneous) views of any two aircraft, their positional data (X, Y, and Z) can be used to predict both the slant range at PCPA and the time to reach the current projection of PCPA. It should be noted that if "s" is negative, the aircraft are diverging and projecting of PCPA becomes the current slant range. If "s" is zero, (which occurs when $C_2 = 0$), the A/C are on parallel courses at identical speeds and the predicted CPA will also equal the current slant range.

Finally, with regard to the prediction of PCPA, the X, Y, and Z coordinates for each aircraft can be predicted for $Time_{i+s}$;

$$\dot{X}_{A_{i+s}} = X_{A_i} + s\Delta X_A \,;\; \dot{Y}_{A_{i+s}} = Y_{A_i} + s\Delta Y_A \,;\; \dot{Z}_{A_{i+s}} = Z_{A_i} + s\Delta Z_A$$

$$\dot{X}_{B_{i+s}} = X_{B_i} + s\Delta X_B \,;\; \dot{Y}_{B_{i+s}} = Y_{B_i} + s\Delta Y_B \,;\; \dot{Z}_{B_{i+s}} = Z_{B_i} + s\Delta Z_B$$

These values can be used to compute the PAPI value for the PCPA projected for $Time_{i+s}$.